Assessment of Strait of Georgia Sport fishing statistics, Sport fishing regulations and trends in Chinook catch using creel survey data.

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April 1986

ASSESSMENT OF STRAIT OF GEORGIA SPORT FISHING STATISTICS, SPORT FISHING REGULATIONS AND TRENDS IN CHINOOK CATCH USING CREEL SURVEY DATA

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ABSTRACT

English, K.K., T.F. Shardlow and T.M. Webb. 1986. Assessment of Strait of Georgia sport fishing statistics, sport fishing regulations and trends in chinook catch using creel survey data. Can. Tech. Rep. Fish. Aquat. Sci. 1375: 54 p.

Analyses conducted in this report are based on data derived from 111,795 angler interviews and 165 aerial surveys conducted through the Georgia Strait Creel Survey Program. Data from the 1980-81 creel survey were used to evaluate the precision and accuracy of the creel survey method and provide a cost-effective design for subsequent surveys. The combination of ramp interviews and aerial surveys allows managers to detect and respond to seasonal and annual changes in the distribution of sport fishing effort. The creel survey program, designed to provide accurate catch and effort statistics for all areas of Georgia Strait, provides a solid basis for assessing changes in chinook and coho abundance in Georgia Strait. Analyses presented in this report suggest that major reductions in chinook catch per effort can be attributed to changes in the abundance of a specific cohort.

The partial failure of a hatchery cohort followed by a major reduction in both sport and troll catches of that cohort suggest that hatchery stocks may comprise a large portion of the total Georgia Strait chinook population. The impact of new sport fishing regulations on total chinook catch was assessed using creel survey data from pre- and post-regulation periods. None of the current regulations have significantly affected sport fishing exploitation rates, which must be dramatically reduced if wild chinook stocks are to survive. Strict catch quotas coupled with accurate in-season catch estimates are the best tools for controlling chinook exploitation in Georgia Strait.

RESUME

English, K.K., T.F. Shardlow and T.M. Webb. 1986. Assessment of Strait of Georgia sport fishing statistics, sport fishing regulations and trends in chinook catch using creel survey data. Can. Tech. Rep. Fish. Aquat. Sci. 1375: 54 p.

Les analyses dont il est fait mention dans le présent rapport sont basées sur des données découlant de 111,795 entrevues avec des pêcheurs à la ligne et de 165 levés aériens réalisés dans le cadre du programme du recensement des prises dans le détroit de Georgie. On s'est servi des données tirées du recensement des prises de 1980-1981 pour évaluer la précision et l'exactitude de la méthode de recensement de prises et pour fournir un modéle rentable pour les levés ultérieurs. Les entrevues et les levés aériens permettent aux questionnaires de déceler les changements saisonniers et annuels dans la répartition de l'effort de pêche sportive et de réagir en conséquence. Le programme de recensement des prises, conçu pour fournir des statistiques précises sur les captures et l'effort de pêche dans tous le secteurs du détroit de Georgie, fournit une base solide pour l'évaluation des changements observés dans l'abondance des saumons quinnat et coho dans le détroit de Georgie. Les analyses présentées dans le présent rapport donnent à penser que la diminution importante des prises de saumon quinnat par unité d'effort peut être attribuée à des changements dans l'abondance d'un stock donné.

L'échec partiel d'un stock de piscifacture et la réduction importante des prises découlant de la pêche sportive et de la pêche à la traîne de ce stock laissent croire que les stocks provenant de piscifactures pourraient comprendre une grande partie de la population totale de saumon quinnat du détroit de Georgie. On à évalué les répercussions des nouveaux réglements de pêche sportive sur les prises totales de saumon quinnat au moyen des données de recensement des prises obtenues avant et après la promulgation desdits règlements. Aucun des règlements actuels n'a influencé de façon importante les taux d'exploitation liés à la pêche sportive, qui doivent être réduits considérablement si l'on veut préserver les stocks sauvages de saumon quinnat. L'imposition de quotas et une estimation précise des prises pendant la saison de pêche sont les meilleurs outils de contrôle de l'exploitation de saumon quinnat dans le détroit de Georgie.

INTRODUCTION

Over the past three years the Department of Fisheries and Oceans has sponsored creel surveys designed to provide monthly catch and effort statistics for the Georgia Strait sport fishery. These creel surveys have provided the desired catch and effort statistics along with other data which have been used to examine the bias, accuracy and precision of these numbers. This paper describes the major analyses performed on the 1980-83 creel survey database, and identifies where the results of these analyses have been used to improve the survey design. This time series of sport fishing statistics has also been used to evaluate recent changes in sport fishery regulations aimed at conserving chinook stocks. Some of the analyses presented in this report were adapted from English et al. (1982).

STUDY AREA AND SCOPE

The Georgia Strait creel survey was designed to produce highly reliable catch and effort statistics for the tidal water sport fishery in Georgia Strait. The study area extended from Sheringham Point near Sooke to Stuart Island north of Campbell River. This area included the southern portion of Statistical Area 13 through Area 19, the eastern portion of Area 20, and Areas 28 and 29, excluding the Fraser River. In 1980-81 Georgia Strait was stratified into 59 sub-statistical areas (DPA 1982). The current creel survey program produces statistics for the same 59 sub-statistical areas, shown in Figure 1.

Data examined in this report are from 111,795 angler interviews and 165 aerial surveys of Georgia Strait conducted between July 1980 and September 1983. DPA Consulting conducted the creel survey for the first 12 months in this period; collecting data from 49,444 interviews and 54 aerial surveys of Georgia Strait (DPA 1982). Subsequent creel surveys conducted by South Coast Division of D.F.O. have compiled data from 62,351 interviews and 111 aerial surveys. Table 1 shows the distribution of these interviews and aerial surveys over the past four years.

BASIC SURVEY METHOD

The basic survey method used to estimate sport fishing catch and effort for the past four years was described in DPA (1982). The method relies upon two separate survey components: 1) landing site surveys and 2) aerial surveys. Landing site surveys are designed to gather information by interviewing anglers at ramps and marinas after completed fishing trips. Data pertaining to species composition of the catch and duration of the trip are recorded. These data are used to calculate catch per boat trip for a catch region (CPE) and the proportion of the days total fishing effort that occurred in a given hour of the day (P).

Aerial surveys are conducted so observers can count all the sport boats (Y) actively fishing in specified sub-regions of Georgia Strait at the time of the survey. The above data can be combined to estimate catch and effort by statistical area and month:

$$\text{EFFORT} = Y \cdot \frac{1}{P}$$

$$\text{CATCH} \quad + Y \cdot \frac{1}{P} \cdot \text{CPE} \qquad \text{CPE}$$

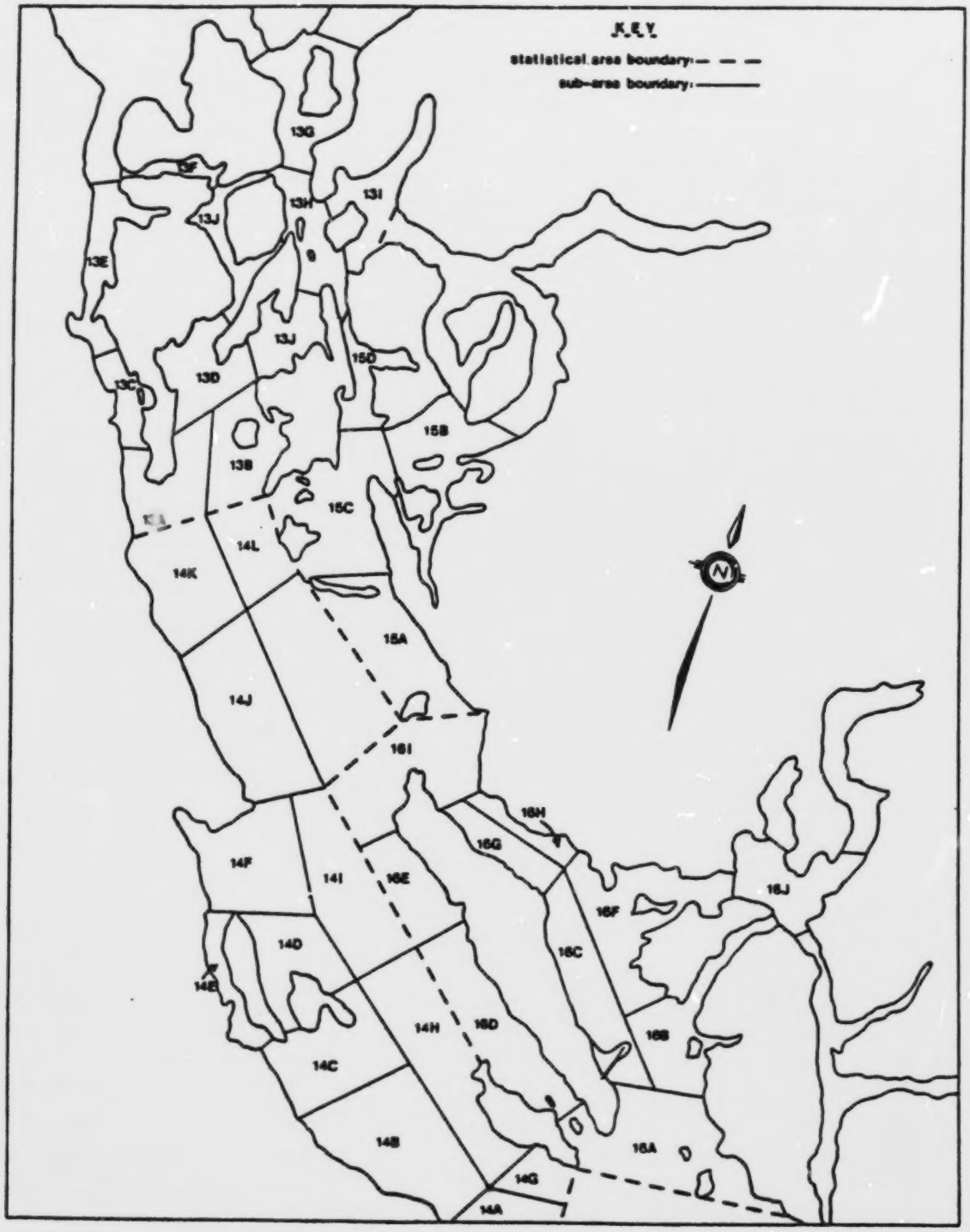


Figure 1a. Sport fishing statistical areas for northern Georgia Strait.

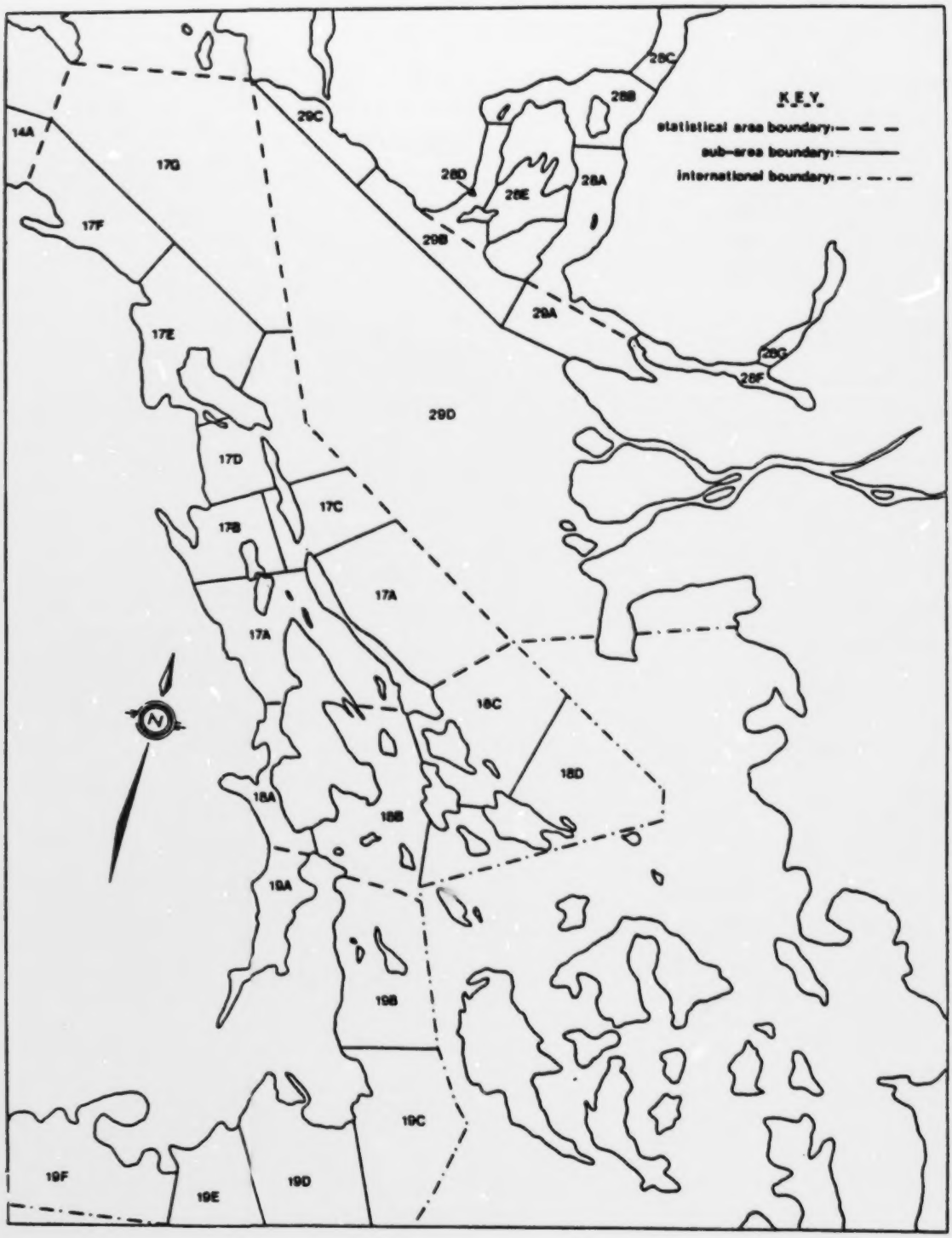


Figure 1b. Sport fishing statistical areas for southern Georgia Strait.

Table 1. Number of creel survey interviews and overflights conducted in each month between July 1980 and June 1983.

	1980		1981		1982		1983	
	Inter-Views	Over-Flights	Inter-Views	Over-Flights	Inter-Views	Over-Flights	Inter-Views	Over-Flights
Jan.			1,335	2	0	1	815	1
Feb.			1,156	2	0	2	1,045	3
Mar.			1,049	4	0	4	900	4
Apr.			954	4	0	0	0	0
May			4,131	4	1,319	2	2,200	4
June			5,349	6	4,141	5	4,400	5
			**	**				
July	15,679	9	8,500	9	5,551	7	4,800	7
Aug.	12,414	8	8,400	8	4,688	7	4,900	7
Sep.	3,839	7	0	0	1,938	7	2,700	7
Oct.	2,368	4	0	0	1,204	5	1,616	4
Nov.	679	2	0	2	825	2	830	2
Dec.	491	2	0	2	833	2	746	2
TOTAL	35,470	32	30,874	43	20,499	44	24,952	46

** Surveys conducted by DPA Consulting July '80 through June '81. Subsequent surveys were conducted by DFO personnel.

where all variables are stratified by day type, interview work block, statistical area and month (see glossary on page 53 for definitions of unfamiliar terms). For a more detailed account of the calculations and the 1980-81 creel survey methods see DPA (1982).

CURRENT CREEL SURVEY

Analyses described in this report have identified areas where the 1980-81 creel survey design could be improved. The current distribution of interviews and timing of aerial surveys is a product of these analyses.

Landing Site Interviews

Thirty separate landing sites were chosen for sampling anglers (Figure 2). Sites were selected so that the busiest landing locations within each of 19 pre-defined geographic landing regions were sampled throughout the year. In the winter months when boat traffic volume is much reduced, the least busy sites were excluded from the survey. This approach is both economical in terms of deployment of field crews and efficient in providing a sample of anglers which best represents the character of sport fishing activities.

Angler interviews involved recording information about an individual boat trip on an interview form (Figure 3). Fourteen interviewers trained in species identification inspected and recorded the species composition of fish retained by anglers. This information was verified by field supervisors and subsequently travelled through a series of editing checks to assure accuracy.

Overflights

The routes flown during the aerial survey were determined on the basis of information from the 1980-81 Georgia Strait Creel Survey. The flight path was designed to cover areas fished by recreational vessels (Figure 2).

In addition the flight path was designed so that areas of major sport vessel concentration were overflown during the hour of the day when the maximum number of vessels were actively fishing. Information from the DPA survey on the proportion of boats fishing by hour of the day was used for this survey to determine the timing of overflights so that peaks in fishing activity by region could be intercepted during a flight.

ANALYSES OF 1980-81 CREEL SURVEY DATA

The 1980 - 1981 Creel Survey provided the most comprehensive set of data ever collected for the Georgia Strait sport fishery. These data have been used to calculate reliable estimates of sport fishing catch and effort, fishing party size, residence and boat type for each statistical area and month (DPA 1982). The following analyses supplement the information presented in the DPA report.

Catch Per Effort by Gear Types

The DPA creel census data were used to calculate catch per effort for 9 statistical areas, 12 months and 24 gear types. Four different effort units were used: (1) boat trip, (2) fishing line trip, (3) fishing line hour, and

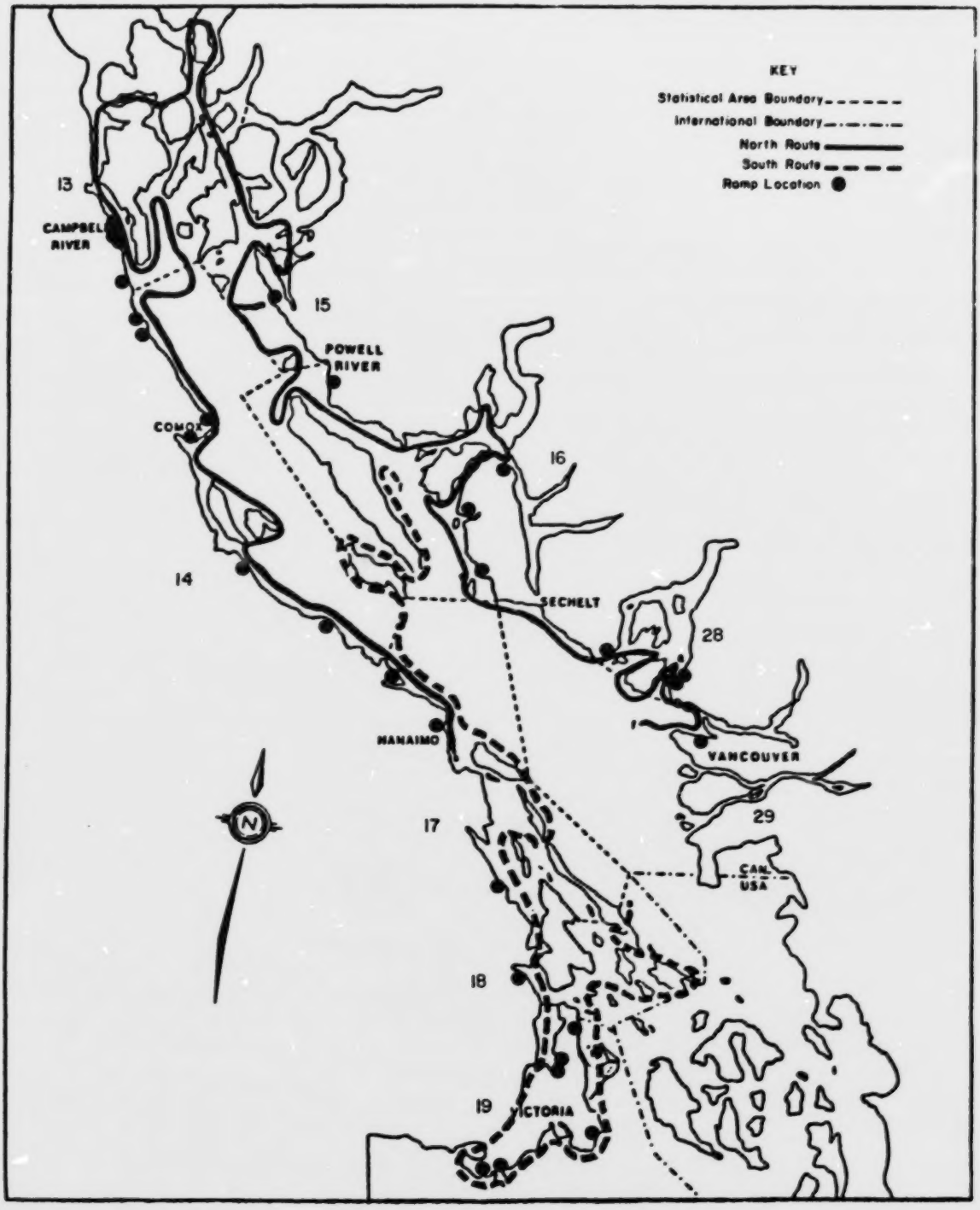
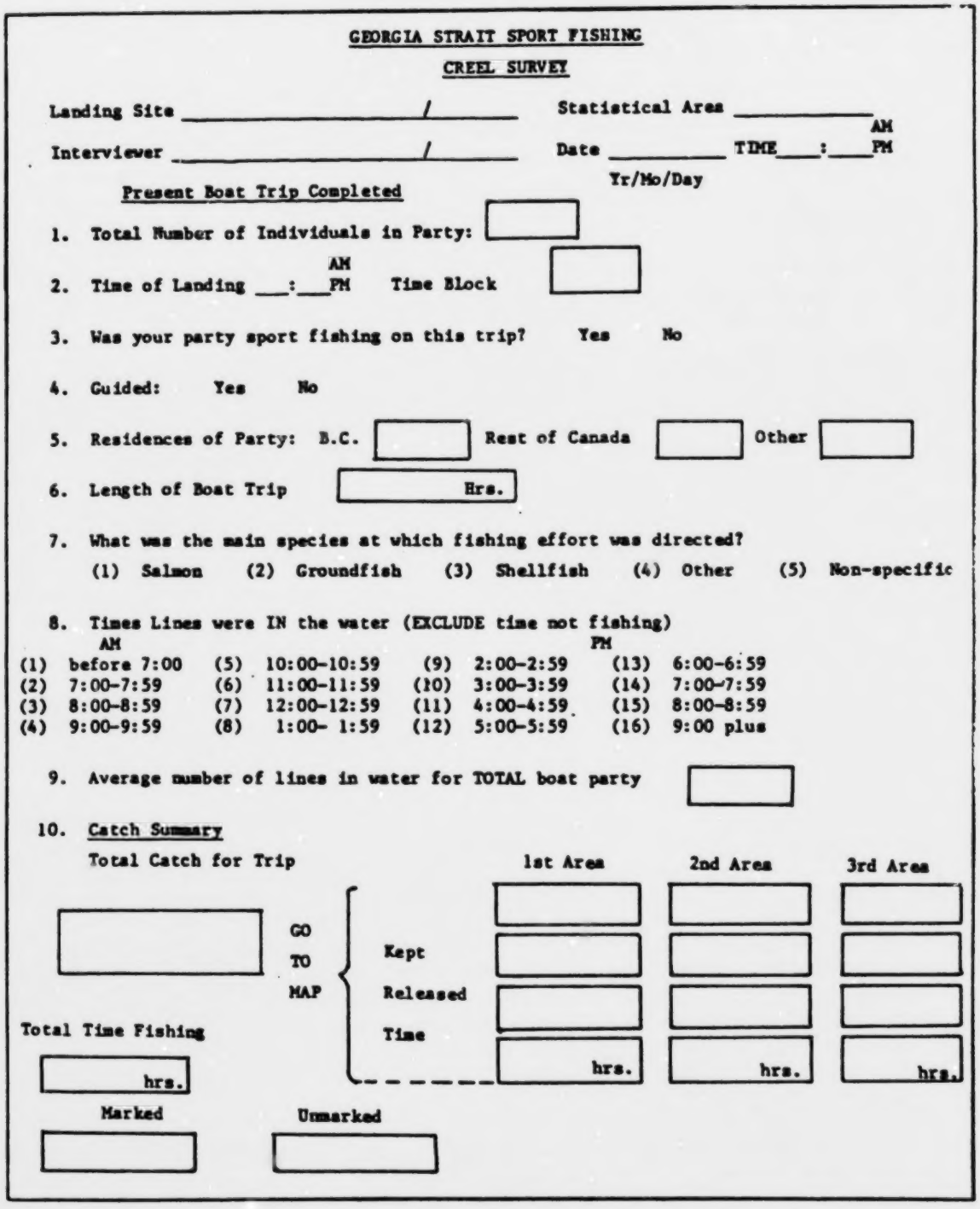


Figure 2. Interview site locations and overflight routes.



GEORGIA STRAIT SPORT FISHING

CREEL SURVEY

Landing Site _____/_____ Statistical Area _____

Interviewer _____/_____ Date _____ TIME ___:___ AM PM

Yr/Mo/Day

Present Boat Trip Completed

1. Total Number of Individuals in Party: [ ]

2. Time of Landing ___:___ AM PM Time Block [ ]

3. Was your party sport fishing on this trip? Yes No

4. Guided: Yes No

5. Residences of Party: B.C. [ ] Rest of Canada [ ] Other [ ]

6. Length of Boat Trip [ ] Hrs.

7. What was the main species at which fishing effort was directed?

(1) Salmon (2) Groundfish (3) Shellfish (4) Other (5) Non-specific

8. Times Lines were IN the water (EXCLUDE time not fishing)

AM				PM			
(1)	before 7:00	(5)	10:00-10:59	(9)	2:00-2:59	(13)	6:00-6:59
(2)	7:00-7:59	(6)	11:00-11:59	(10)	3:00-3:59	(14)	7:00-7:59
(3)	8:00-8:59	(7)	12:00-12:59	(11)	4:00-4:59	(15)	8:00-8:59
(4)	9:00-9:59	(8)	1:00- 1:59	(12)	5:00-5:59	(16)	9:00 plus

9. Average number of lines in water for TOTAL boat party [ ]

10. Catch Summary

Total Catch for Trip		1st Area	2nd Area	3rd Area
[ ]	GO TO MAP			
	Kept	[ ]	[ ]	[ ]
	Released	[ ]	[ ]	[ ]
	Time	[ ]	[ ]	[ ]
		hrs.	hrs.	hrs.

Total Time Fishing

[ ] hrs.

Marked [ ] Unmarked [ ]

Figure 3. Sample of interview form. Gear type information on the 1980-81 interview form has been deleted.

(4) angler trip. Catch per boat trip had the smallest coefficient of variation (standard deviation divided by the mean) for most fishing methods.

The means and standard deviations of catch per effort and released fish per effort were calculated for coho and chinook salmon. Variances of the means were calculated using the following standard variance formula:

$$S^2_{\bar{x}} = \frac{\sum x^2 - \frac{(\sum x)^2}{n}}{n(n-1)}$$

where x is the unweighted catch by statistical area, month, method and species for each interview and n is the number of interviews in each category.

Catch efficiencies for each gear type have been summarized for all statistical areas and months. Table 2 shows that chinook catch efficiency was significantly higher for fishermen using downriggers than any other method. Of the top four methods used to catch coho, trolling was the most effective and there were no significant differences among the catch efficiencies for the other three methods (Table 3). There were no significant differences among the top four methods for catching fish that were subsequently released; however, the released fish per effort values were much higher for lures than bait (Table 4).

It is generally believed that more experienced fishermen use bait rather than lures[1] and more experienced fishermen can avoid catching under-sized fish. Another explanation for lower shaker catches when bait fishing is that bait (herring) tends to be larger than most lures. Smaller lures tend to catch smaller fish.

Awareness Factor

The awareness factor is the average probability that an angler will turn in the head of a marked fish (adipose fin removed). Until 1981 catch statistics from the Head Tag Recovery Program were based on an awareness factor of 0.2, derived from the Puget Sound sport fishery. The major limitation of these catch statistics has been that confidence limits could not be defined without statistically-based estimates of the awareness factor. The 1980-81 creel survey has provided sufficient data to estimate awareness factors for B.C. tidal sport fishermen.

The DPA data were used to estimate the proportion of marked to unmarked fish caught by B.C. tidal sport fishermen each month for all statistical areas in Georgia Strait. Assuming a binomial distribution, the variance of this proportion can be calculated using the following equation:

$$S^2_{\bar{P}_m} = \frac{\bar{P}_m(1-\bar{P}_m)}{n}$$

where $\bar{P}_m$ is the average proportion of marked to unmarked fish in the catch and n is the total number of fish inspected for marks.

[1]The exception to this gear type choice by anglers is plug fishing where some advanced anglers use plugs; however, plug fishermen are rare in the Georgia Strait sport fishery.

Table 2. Chinook catch per effort by gear type or combinations of gear types.

	No. of Chinook Caught Per Trip		
	Mean	Standard Deviation	No. of Interviews
Downrigger	1.17	0.08	524
Troll/Downrigger/Planing	0.85	0.02	5,139
Planing	0.60	0.06	400
Casting	0.51	0.04	878
Mooching	0.40	0.01	6,438
Trolling	0.39	0.01	20,933
Jigging	0.35	0.03	1,356
Trolling/Mooching	0.23	0.02	2,118
Bait and Lure	0.51	0.01	8,850
Lure	0.45	0.01	17,090
Bait	0.43	0.01	13,964

Table 3. Coho catch per effort by gear type or combinations of gear types.

	No. of Coho Caught Per Trip		
	Mean	Standard Deviation	No. of Interviews
Trolling	0.91	0.01	20,933
Trolling/Downrigging/Planing	0.72	0.02	5,139
Mooching	0.72	0.02	6,438
Casting	0.71	0.06	878
Planing	0.66	0.08	400
Trolling/Mooching	0.58	0.03	2,118
Downrigging	0.43	0.05	524
Jigging	0.25	0.03	1,356
Lure	0.92	0.01	17,090
Bait	0.72	0.01	13,964
Bait and Lure	0.58	0.01	8,854

Table 4. Salmon released per effort, by gear type or combinations of gear types.

	No. of Salmon Released Per Trip		
	Mean	Standard Deviation	No. of Interviews
Downrigging	0.96	0.10	524
Trolling/Downrigging/Planing	0.89	0.03	5,139
Trolling	0.76	0.02	20,933
Planing	0.74	0.09	400
Casting	0.68	0.08	878
Trolling/Mooching	0.60	0.04	2,118
Jigging	0.34	0.06	1,346
Mooching	0.28	0.02	6,438
Bait and Lure	0.91	0.03	8,850
Lure	0.74	0.02	17,090
Bait	0.45	0.01	13,964

Marked to unmarked ratios and catch statistics were multiplied to estimate the total number of marked fish caught by B.C. sport fishermen. The variance of the estimated number of marked fish caught was calculated using the following equation for the variance of a product (Goodman 1960):

$$S^2_{\bar{m}_C} = \left(\bar{P}_m \cdot S^2_{\bar{C}}\right) + \left(\bar{C} \cdot S^2_{\bar{P}_m}\right) + \left(S^2_{\bar{P}_m} \cdot S^2_{\bar{C}}\right)$$

where $\bar{C}$ represents the mean catch, $S^2_{\bar{C}}$ represents the variance of the mean catch and other variables are described above.

Means and variances of awareness factors were calculated using the significant terms of a Taylor series expansion (Cochran 1963):

$$\bar{A} = \frac{m_T}{\bar{m}_C}$$

$$S^2_{\bar{A}} = \frac{m_T^2}{\bar{m}_C^2} \cdot \left(\frac{S^2_{m_T}}{m_T} + \frac{S^2_{\bar{m}_C}}{\bar{m}_C^2}\right)$$

where $\bar{A}$ is the mean awareness factor, m_T is the number of marked fish turned in and $\bar{m}_C$ is the estimated number of marked fish caught. The variance of the awareness factors $S^2_{\bar{A}}$ was calculated assuming that the variance of the number of marked fish turned in $S^2_{m_T}$ is zero (i.e., an accurate count).

These analyses revealed that the average awareness factors for sport fishermen in Georgia Strait were 0.262 and 0.174 for coho and chinook, respectively. The 95% confidence intervals for each of these 1980-81 values

were less than 10%. On finer spatial or temporal scales the confidence intervals become much wider, and in some areas and months proper statistics could not be calculated (Tables 5 and 6). In some categories, the numbers of heads turned in were greater than the estimated number of marked fish caught (Table 5, June and Statistical Area 28). These observations suggest that estimates of catch for specific months and statistical areas should not be based on estimated awareness factors .

BIASES AND VARIANCES

This analysis investigates some of the biases and variances inherent in a creel census of the type used in Georgia Strait during 1980-81. This type of creel survey involves two separate sampling routines:

1. A fixed stint survey where fishermen having completed a boating trip supply information on two topics:

   a. catch by species;
   b. times of day in which they fished.

2. A benchmark effort survey - a snapshot, usually an overflight, which gives an estimate of the total effort at that time.

These two components can then be combined to give estimates of total effort and total catch.

In the analysis below, the sources of variability will be discussed; then their implications will be investigated using Monte Carlo simulations and other techniques.

Sources of Variation

Activity Pattern

The activity pattern for a given stratum is obtained from the interview data on which time blocks were fished (see Figure 3). Thus for each fishing trip interviewed there is either a yes or no response to the question "were lines in the water" for each time block. These responses can be combined over all interviews to give an estimate of the proportion of boats fishing which were actively fishing at each time - the activity pattern. In order to allow for varying sampling efforts during the day appropriate weighting factors are used.

The proportion of daily boat trips fishing at various times during the day, the activity pattern, is formed using the relationship:

$$P_i = \frac{\sum_{j}^{NS}\sum_{k}^{NB} FT_{ijk} \cdot W_{jk}}{\sum_{j}^{NS}\sum_{k}^{NB} \left(\sum_{i} FT_{ijk}\right) \cdot W_{jk}} \qquad (1)$$

Table 5. The ratio of coho heads turned in to estimated number of marked coho caught (awareness factor) by month and statistical area, July 1980 to June 1981. Blanks indicate heads were turned in but no marks were observed during interviews.

Month		Statistical Area									Monthly Mean
		13	14	15	16	17	18	19	28	29	
JUL.	MEAN	0.218	0.372	0.403	0.169	0.275		0.567	0.373	0.013	0.243
	STE	0.023	0.044	*	0.023	0.060		0.207	0.084	0.004	0.014
AUG.	MEAN	0.178	0.529	0.236	0.289	0.399		0.375	0.338	0.034	0.239
	STE	0.015	0.085	*	0.056	*		0.147	0.048	0.008	0.014
SEP.	MEAN	0.238	0.872	0.045	0.169	0.172		0.0	0.138	0.118	0.212
	STE	0.051	*	0.010	*	*		0.0	0.032	*	0.025
OCT.	MEAN	0.280	0.807		0.335	0.176	0.0	0.257	0.649		0.357
	STE	0.129	0.530		*	*	0.0	*	*		0.076
NOV./ DEC.	MEAN			0.0				0.160	0.0	0.0	1.372
	STE			0.0				*	0.0	0.0	*
JAN./ FEB.	MEAN		0.135	0.0		0.771		1.259		0.0	0.662
	STE		*	0.0				*		0.0	0.279
MAR.	MEAN		0.0	0.0						0.0	
	STE		0.0	0.0						0.0	
APR.	MEAN	0.061	0.241		0.053	1.595					0.270
	STE	*	0.076		0.028	*					0.069
MAY	MEAN	0.145	0.470	0.321	0.160	0.643	0.130		1.290		0.388
	STE	0.037	0.063	0.305	0.041	0.200	*		*		0.038
JUNE	MEAN	0.214	0.384	0.156	0.174	0.362	0.076		2.691		0.265
	STE	0.063	0.084	0.076	0.042	0.071	*		*		0.038
ANNUAL	MEAN	0.196	0.436	0.096	0.178	0.451	0.122	0.503	0.367	0.030	0.262
	STE	0.015	0.036	0.018	0.015	0.048	*	0.109	0.038	0.005	0.010

* Insufficient sample size to calculate standard error (STE) of the estimate ($p \cdot q \cdot n < 5$).

Table 6. The ratio of chinook heads turned in to estimated number of marked chinook caught (awareness factor) by month and statistical area, July 1980 to June 1981. Blanks indicate heads were turned in but no marks were observed during interviews.

Month		Statistical Area									Monthly Mean
		13	14	15	16	17	18	19	28	29	
JUL.	MEAN	0.467	0.703		0.223	0.092		0.278	0.258	0.008	0.251
	STE	0.146	0.274		0.064	0.030		0.116	0.095	0.003	0.033
AUG.	MEAN	0.220	0.378		0.366	0.201	0.195	0.087	0.451	0.010	0.237
	STE	0.044	0.086		0.140	*	*	0.030	*	0.003	0.027
SEP.	MEAN	0.176	0.953		0.524	0.027	0.150	0.143	0.198	0.064	0.225
	STE	*	*		*	0.011	*	0.050	*	*	0.041
OCT.	MEAN		0.323		2.385	0.110		0.298	0.045		0.299
	STE		*		*	0.047		0.094	*		0.064
NOV./	MEAN				0.123	0.107	0.046	0.593	0.035	0.058	0.152
DEC.	STE				0.064	*	0.018	*	*	*	0.033
JAN./	MEAN				0.538	0.032	0.059	0.290	0.036	0.028	0.150
FEB.	STE				*	0.009	*	*	0.015	*	0.027
MAR.	MEAN		0.0	0.0		0.092	0.032		0.463	0.0	0.242
	STE		0.0	0.0		*	0.021		*	0.0	*
APR.	MEAN	0.043	0.013	0.0	0.044	0.048		0.174	0.279	0.0	0.058
	STE	*	0.005	0.0	*	*		*	*	0.0	0.015
MAY	MEAN	0.098	0.158		0.013	0.505	0.007	0.195	0.067	0.0	0.086
	STE	0.037	0.043		0.005	0.329	0.004	0.140	0.026	0.0	0.012
JUNE	MEAN	0.231	0.197	0.062	0.020	0.134	0.017	0.137	0.187	0.0	0.104
	STE	0.096	0.056	*	0.004	0.057	*	*	0.054	0.0	0.013
ANNUAL	MEAN	0.268	0.323	0.140	0.138	0.097	0.056	0.203	0.174	0.013	0.174
	STE	0.037	0.040	*	0.018	0.013	0.012	0.030	0.025	0.002	0.009

* Insufficient sample size to calculate standard error (STE) of the estimate ($p \cdot q \cdot n < 5$).

where

P_i = proportion of daily fishing trips that included fishing time block i,

FT_{ijk} = number of fishing trips that included fishing time block i that landed at site j during interview work block k,

W_{jk} = a weighting factor which adjusts interview data for sampling effort both within and between work blocks. (i.e., if 10% of the morning work blocks in a month were worked and 50% of the boats landing were interviewed the weight factor would be 20.),

NS = number of landing sites sampled,

NB = number of interview work blocks (normally 4 per day).

There are two sources of variation associated with the activity pattern:

1. variation in the daily behaviour pattern of the fishermen, possibly in response to weather or catch per unit effort; and

2. variation due to sampling.

Due to the structure of the creel survey, activity patterns can only be calculated on a monthly basis. This means that the daily variation in angler behaviour cannot be investigated.

The variation associated with the proportion of the daily boat trips fishing (P) in any one time block arise from a series of questions with a certain probability of a yes answer (e.g., was a particular boat fishing in a stated time block?). Since, in general, the number of interviews is large, we can estimate the variance as:

$$\frac{P(1-P)}{N}, \qquad (2)$$

where
P = proportion of yes answers, and
N = total # of interviews.

Unfortunately, this method does not take into account the relationship between adjacent time blocks which becomes important where there is uncertainty as to the exact timing of an overflight ($\pm$30 minutes for the 1980-81 creel surveys).

Overflight Counts

There are three possible sources of error associated with the overflight counts:

1. Errors in counting -- in the creel survey, estimated counting errors were minimal; this may not always be the case in this type of survey.

2. Errors in timing -- due to the one hour time block used in the creel survey, the overflight time could only be estimated with precision of ±30 minutes. This inaccuracy represents quite a large range of activity values on some parts of the proportion of active boat's curves.

3. Daily variations -- if overflight counts are made at a particular time on every day of a particular day type within a month with no counting or timing errors, then the mean number of boats fishing at that time is known exactly. If not all the days are sampled, then the variance of the estimate of the mean can be estimated using a correction for sampling from small populations (Goodman 1960):

$$VAR\,\bar{x} = \frac{VAR\,x}{n}\left(\frac{N-n}{N-1}\right) \qquad (3)$$

where

VAR $\bar{x}$ = variance of estimate of mean,
VAR x = sample variance,
N = total # of days available, and
n = # days sampled.

Catch Per Effort

Catch per boat trip depends on the number of anglers per boat, the efficiency of these anglers and the random variation in their encounters with fish. In the Monte Carlo analysis the observed distributions of catch per effort were used. This approach avoids making assumptions about the form of the variation in catch per effort.

Distribution of Catch Per Effort Estimates

Even though the observed distributions of catch per effort were used in the Monte Carlo analyses it is interesting to attempt to fit theoretical distributions to these data. Fitted theoretical distributions could then be used to predict the immediate reductions in catch due to reduced daily bag limits.

Two consistent characteristics were noted during an analysis of catch per effort estimates for several different strata:

1. The observed distributions can be fitted by negative binomial distributions; and

2. the negative binomial parameter (k) from the fitted distributions is correlated with the mean.

Table 7 shows the negative binomial distribution fitted to two example strata.

Table 7. Catch per boat trip for two strata with fitted* negative binomial distributions.

	Stratum 1: March Weekends in Victoria		Stratum 2: July weekdays in West/North Vancouver	
Caught	Observed	Fitted	Observed	Fitted
0	220	220	195	195
1	54	64	52	46
2	39	33	21	21
3	18	19	6	12
4	18	12	6	7
5	9	7	6	4
6	2	5	0	2
7	1	3	1	2
8	6	2	3	1
9	2	1		
$x^2_{DF=7}$ = 10.51			$x^2_{DF=5}$ = 3.69	
0.1 < P < 0.25			0.5 < P < 0.75	
1/K = 2.47			1/K = 2.92	

*K parameter fitted using the proportion of zeros method (Anscombe 1950).

The regression equation relating K to the mean was found to be:

$$\hat{K} = 0.39\ CPE + 0.07 \qquad (4)$$

with R^2=0.86 and P<0.001. In addition to this relationship which is particular to the above catch per effort data and relates to comparisons between different samples, there is a relationship between K, the mean and the variance within a given sample from a negative binomial distribution (Anscombe 1950):

$$\hat{K} = \frac{\bar{x}^2}{VAR(x) - \bar{x}} \qquad (5)$$

These two equations can be combined in the following manner: Given a particular mean catch per effort the negative binomial parameter K can be estimated using equation 4; once K and the mean are determined equation 5 can be used to estimate the variance. Therefore, for any given mean catch per effort the form of the variation around that mean can be estimated.

Variance Estimation

Two methods of estimating the standard error of effort and catch estimates are available: mathematically combining the means and variances of the components, and using Monte Carlo methods to simulate the sampling process. Both methods should provide underestimates as they do not include any information concerning the behavioural variability of the fishermen. However, the Monte Carlo method should give a better estimate because it includes the effect of errors in overflight timing.

Monte Carlo Analysis

The objective of this analysis was to understand better the relative contributions of the components of the variance described above. Most of the analysis concentrated on one stratum (July weekends in the Victoria area) with other strata used to check generality. In each simulated survey four components were estimated:

(1) Proportion of active boat trips;
(2) Catch per unit effort;
(3) Overflight boat counts; and
(4) Timing of overflight boat counts.

In order to recreate the sampling process which produced the activity pattern, the 1980-81 Creel Survey data were structured in the following manner. Boats landing in a particular stratum were segregated into 64 categories -- 16 landing blocks and 4 possible delays (times between stopping fishing and landing). Within each of these categories, the proportion of trips in each of 16 landing blocks (0-16 hours) was noted. This matrix was used to reconstruct the activity pattern for a given stratum.

In each interview work block in each site, the number of fishing boats landing was drawn from a normal distribution with the mean and variance observed for that site and work block. A fixed proportion of boats landing was assumed to be interviewed. For each interview, two random choices were made:

1. the length of time between stopping fishing and landing; this varied between 0 and 3 hours and was picked randomly using the observed proportions; and

2. the trip length; this was picked randomly using the observed proportions.

Weighting factors were calculated based on the proportion of boats interviewed and the proportion of work blocks sampled (see equation 1).

Mean CPE's and their variances were produced by randomly sampling the observed distribution the required number of times (1000).

The distribution of overflight counts was assumed to be normal with the observed mean and a variance calculated using Equation 3 described above which includes a correction factor for sampling from a small population without 'replacement'. Due to the small number of overflights (2-6), there is a problem in accurately estimating the overflight variance. In what follows, the observed variance will be used; however, in the future it may be better to use a different method of estimating overflight variances.

In 1980-81 overflight timings were recorded to the nearest hour. The effect of this level of precision on the variance estimate for effort was estimated by drawing random numbers from within a one hour period to determine the overflight time and subsequently selecting the proportion of the daily boat trips active at that time.

Figure 4 shows a typical activity pattern with bars representing the Monte Carlo estimates of two standard errors. Figure 5 shows the effects of the number of interviews on this standard error in the form of a coefficient of variation; this figure was derived from five Monte Carlo runs.

The curve shown in Figure 5 closely resembles what would be expected if equation 2 had been used to estimate variance for the proportion of active boat trips. However, the method used produces the activity pattern from overlapping trips of various lengths simulating the actual sampling process. This results in a realistic relationships between the activities in consecutive time blocks (i.e. a smooth curve over time). If the activity for each time block were picked randomly and independently then the activity pattern would tend to be uneven with irregular changes in slope. The form of the activity curve (smooth versus uneven) becomes important when it interacts with the uncertainty in overflight timing.

Figure 6 shows the effects of overflight timing on the coefficient of variation of the effort estimate for another stratum. This pattern is produced by two interacting effects:

1. Timing uncertainty - the degree to which uncertainty in overflight timing (±30 minutes) effects the variance of the effort estimate depends on the rate of change in the activity curve. In time blocks 4 and 5 in Figure 6 the slope is small so that timing uncertainty has little effect and the variance of the effort estimate is low. In time block 6, however, the slope is greater and the variance is thus higher.

2. Proportion magnitude - the coefficient of variation of a proportion can be estimated by:

$$\sqrt{\frac{\frac{1}{p}-1}{N}} \qquad (6)$$

The value of this function increases rapidly for values of p less than 0.2. This effect causes the marked increase in coefficient of variation as the proportion drops in the last few time blocks of Figure 6.

The curve for coefficient or variation of the effort estimate in Figure 6 was produced using five separate Monte Carlo runs with overflight times in five different time blocks.

Figure 7 shows a curve representing the effect of reducing the number of interviews on the coefficient of variation of catch. The curve was derived using 'July, weekend, Victoria' parameters (means, variances, etc.) in the Monte Carlo model. Values calculated using parameters for other strata are also plotted for comparison.

The two points that deviate from the plotted curve do so because of much higher coefficients of variation for their overflight counts. As noted previously, these high variances may be artifacts due to the small sample size.

If the curve of Figure 7 is calculated for a series of different numbers of overflights, then they can be used to draw the contours shown in Figure 8.

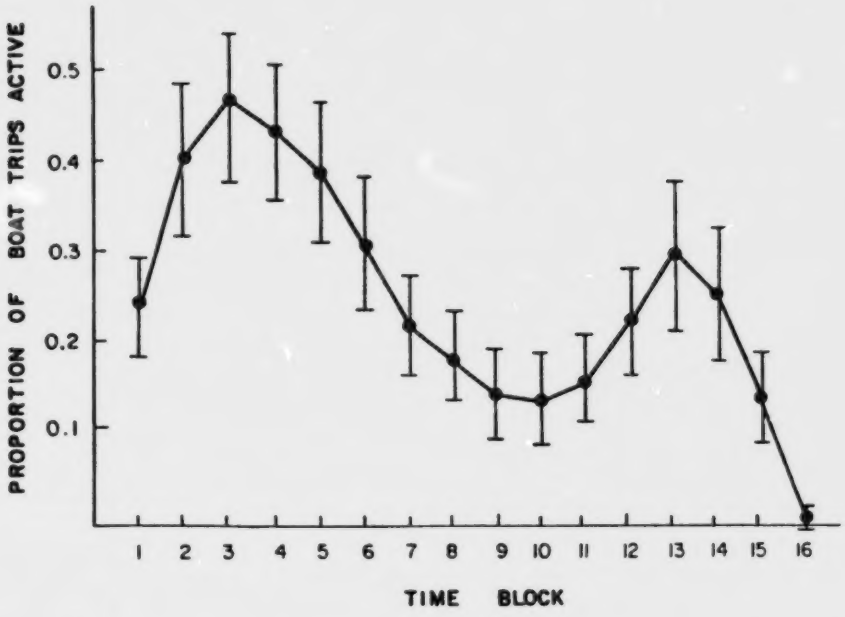


Figure 4. An example of a curve of proportion of active boat trips. Limits are ± 2 standard errors.

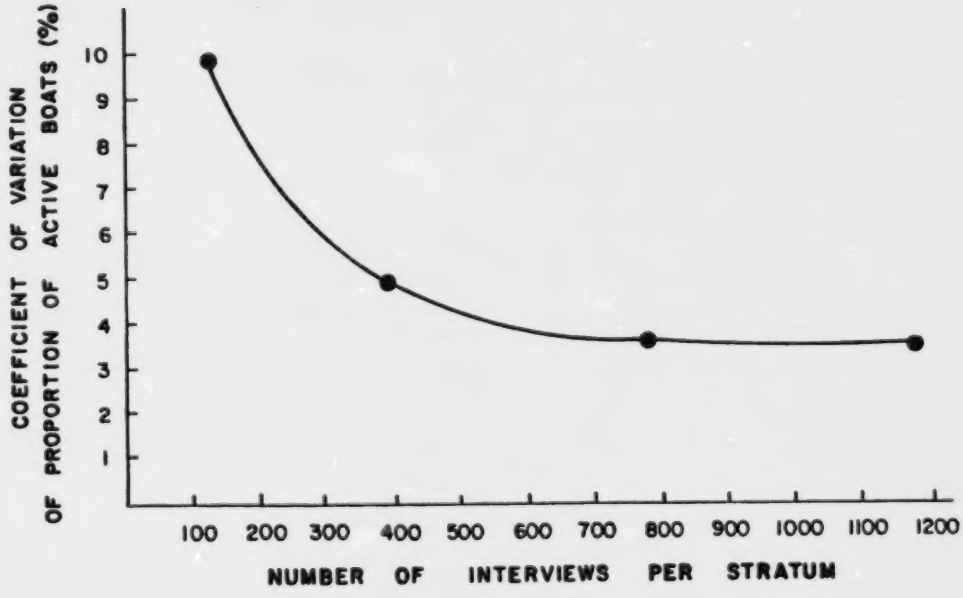


Figure 5. Effect of number of interviews on the coefficient of variation of the proportion of active boat trips.

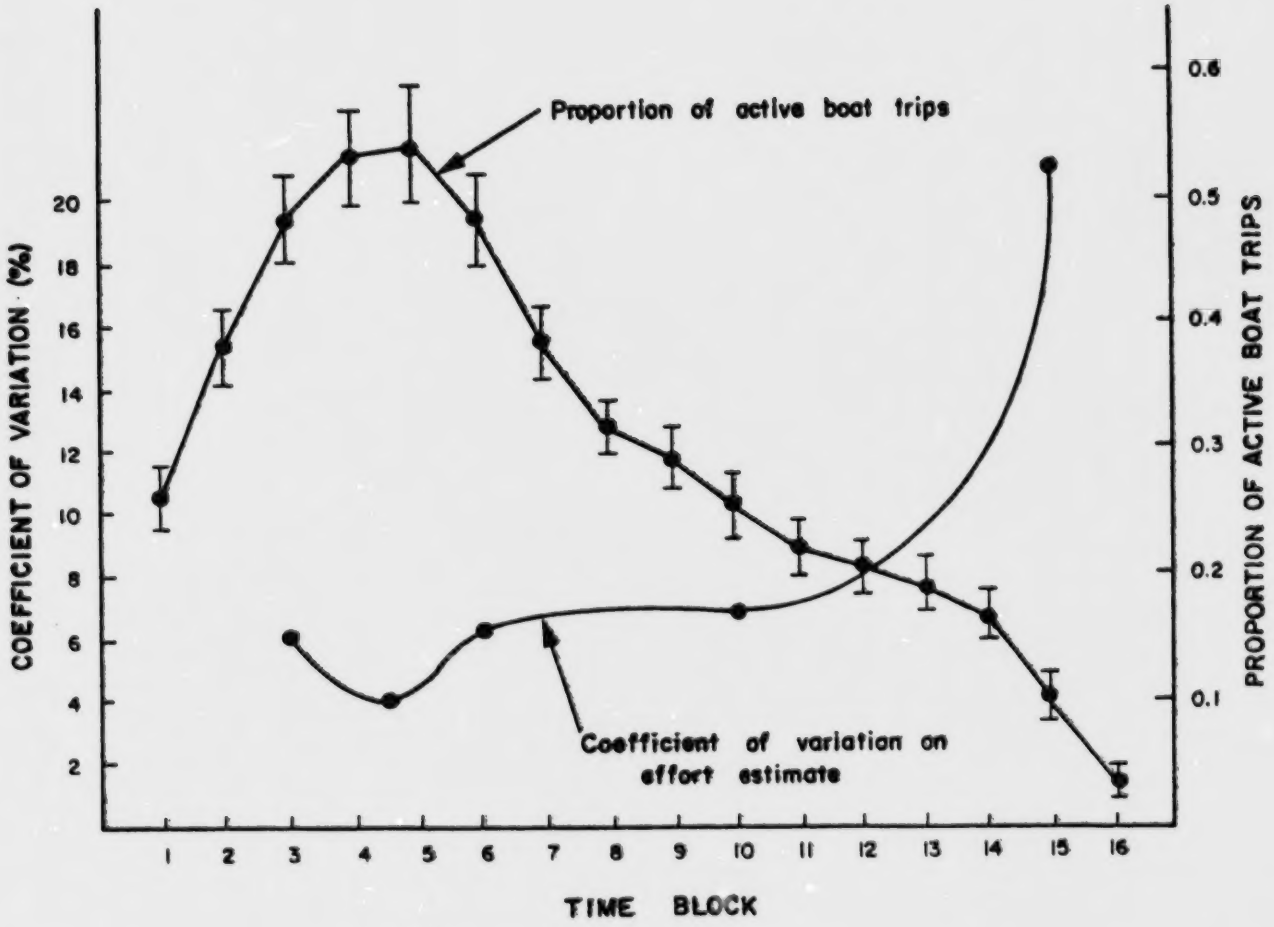


Figure 6. Effect of overflight timing on the coefficient of variation of the estimate of effort (Data used was July weekends in Victoria).

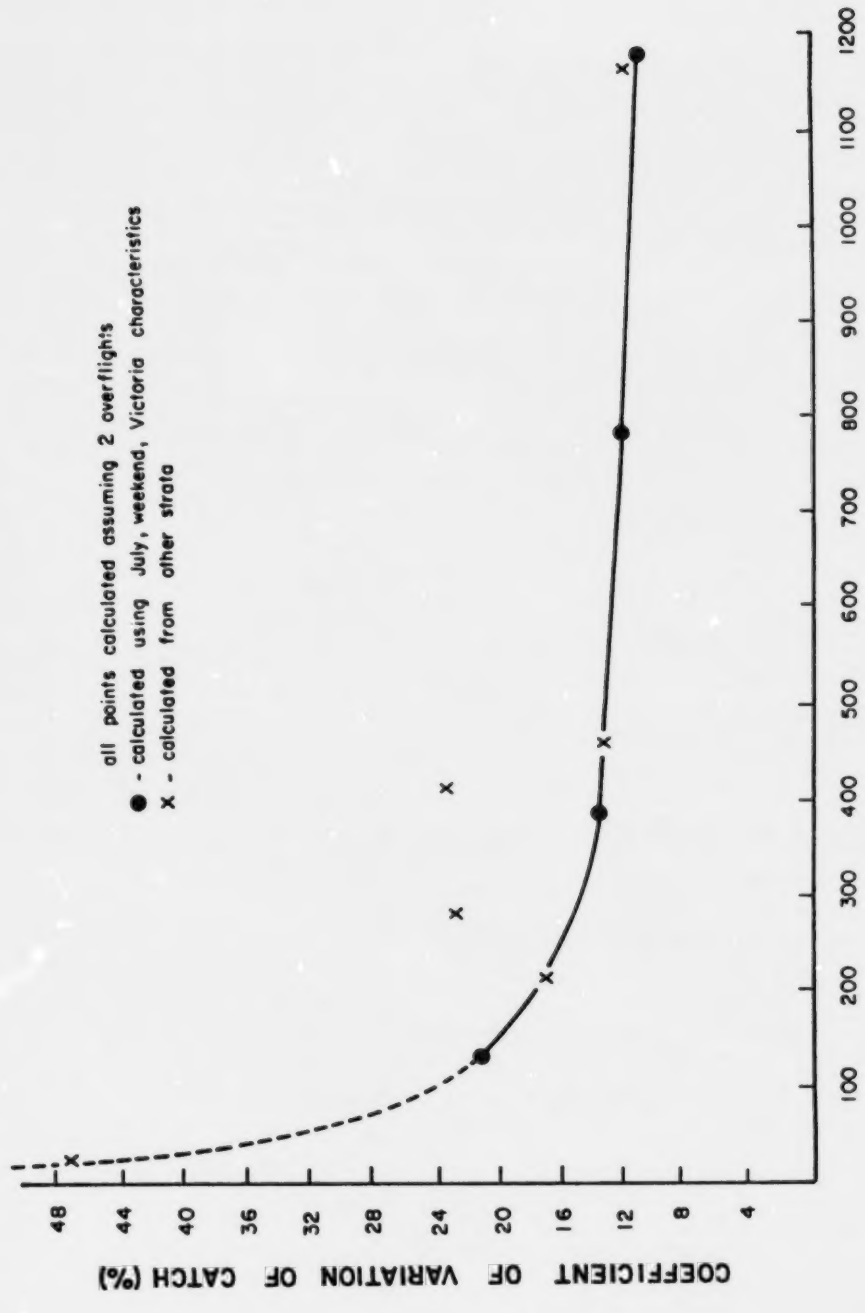


Figure 7. Coefficient of variation as a function of number of interviews.

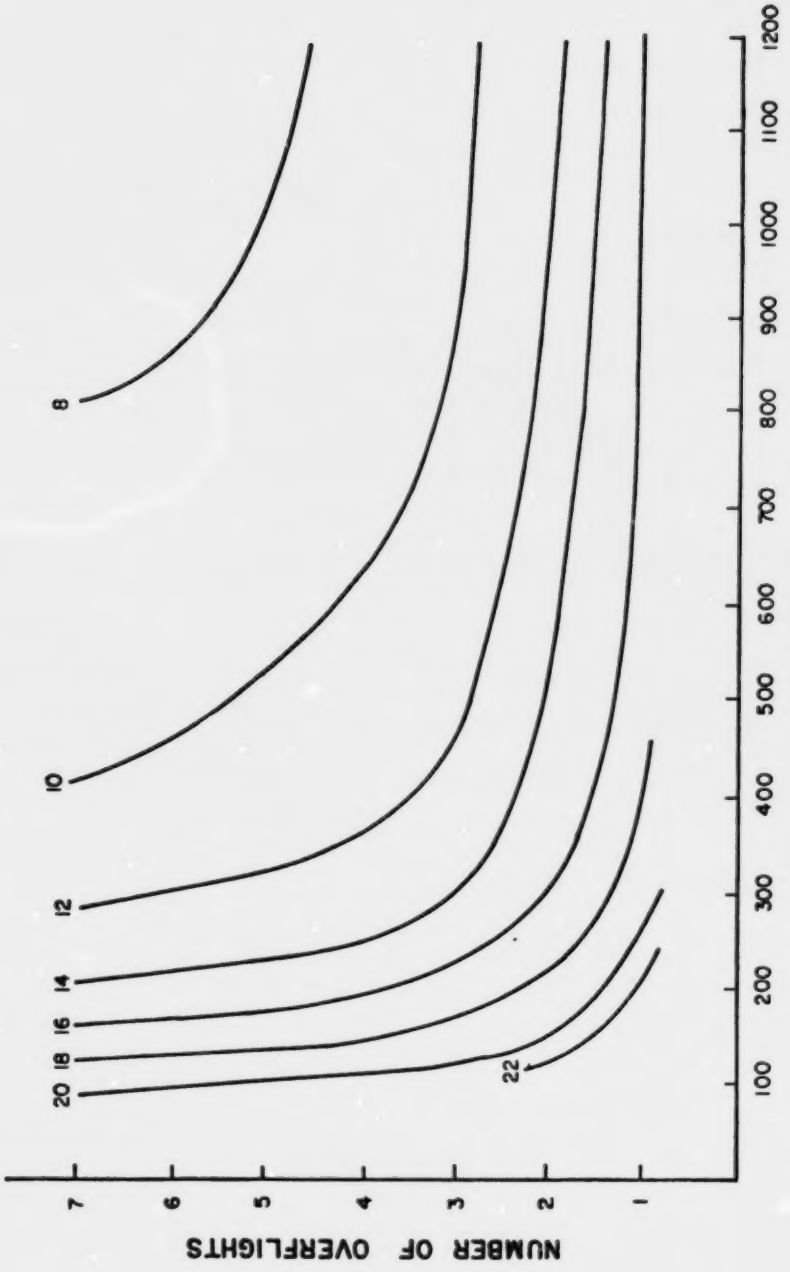


Figure 8. Coefficient of variation of catch (%) as a function of number of interviews and number of overflights.

between the sampling intensities of the two parts of the survey - the overflights and the interviews. Strictly speaking, these diagrams only relate to 'July weekend, Victoria', however, the results from other strata (Figure 7) are close enough that some degree of generalization is possible.

The values obtained using Figure 8 do not take into account the effects of sampling from a limited population. This can be corrected (approximately) by multiplying the variance by a correction factor (F):

$$F = \left(\frac{N-n}{N-1}\right)^{\frac{1}{2}} \qquad (7)$$

where N is the population size (total number of landings) and n is the sample size (number of landings sampled).

Figure 9 shows the correction factor plotted for all values of the proportion of the population sampled. In 1980-81 fewer than 15% of all landings at any site were sampled, therefore, this factor would not have been significant. The shape of this curve is important; it means that in low volume sites large proportions of landings must be sampled in order to obtain reasonable confidence limits.

If the main constraint on sampling is cost, then the aim in sampling should be to minimize the error given the constraint that:

Cost = # overflights·overflight cost + # interviews·interview cost

Realistic average costs have been estimated by fisheries personnel as:

overflight cost = \$150.00 per stratum
interview cost = \$1.50 per interview

The interview cost will vary widely at different times of the year and in different areas, as it is calculated as the cost per stint (\$50.00) divided by the number of interviews in that stint. A stint represents a 7-8 hour work shift for a creel survey interviewer working at a single landing site. Since the number of boats landing in a stint varies between 2 and 100, the cost will vary in a similar fashion.

Figure 10 shows lines of equal cost superimposed on the nomogram of coefficient of variation of catch. From this diagram optimal combinations of overflights and interviews can be estimated; altering the cost of interviews alters the slope of the lines in Figure 10 and thus changes the optimal combination.

The discussion so far has centred on effort allocation within a stratum, the other part of the problem concerns effort allocation between strata. If we ignore the possibilities of bias the most cost effective approach is to get as many interviews as possible from the cheapest strata (busiest landing sites); ignoring cost effectiveness would lead us to sample all landing sites in proportion to their traffic volume. These two approaches cannot be easily reconciled. The most reasonable approach would be to identify the busiest landing sites but to allocate sampling effort between busy sites on a stratified random basis.

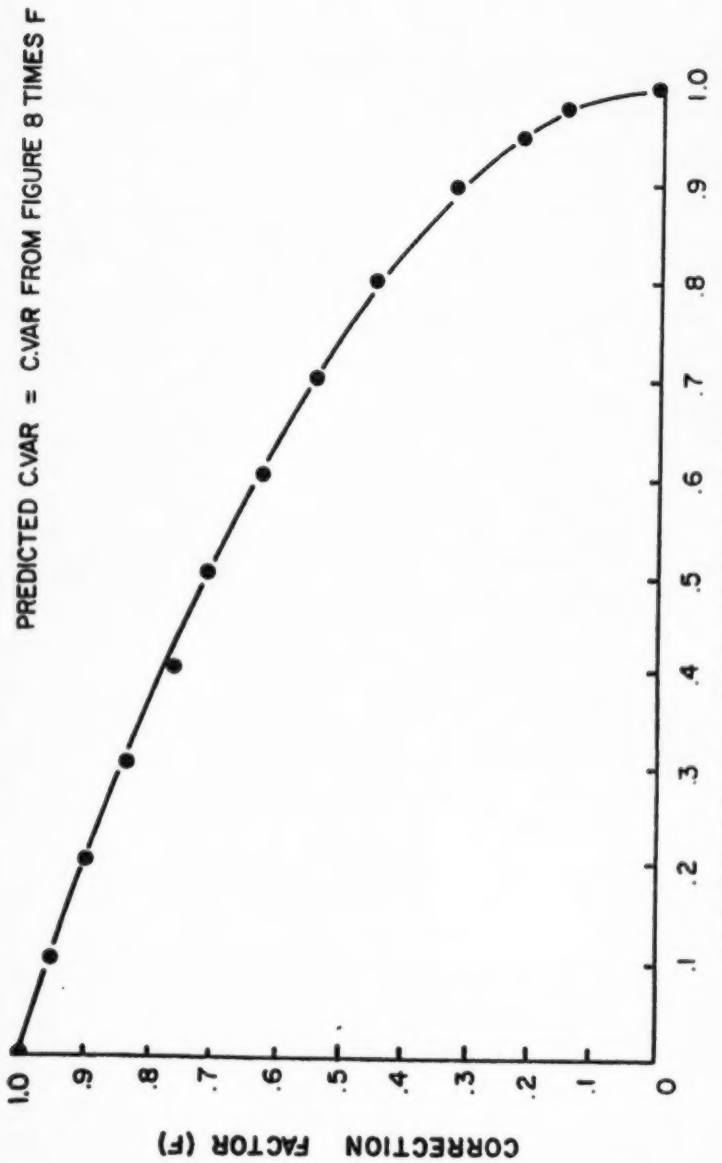


Figure 9. Correction factor for sampling from a limited population.

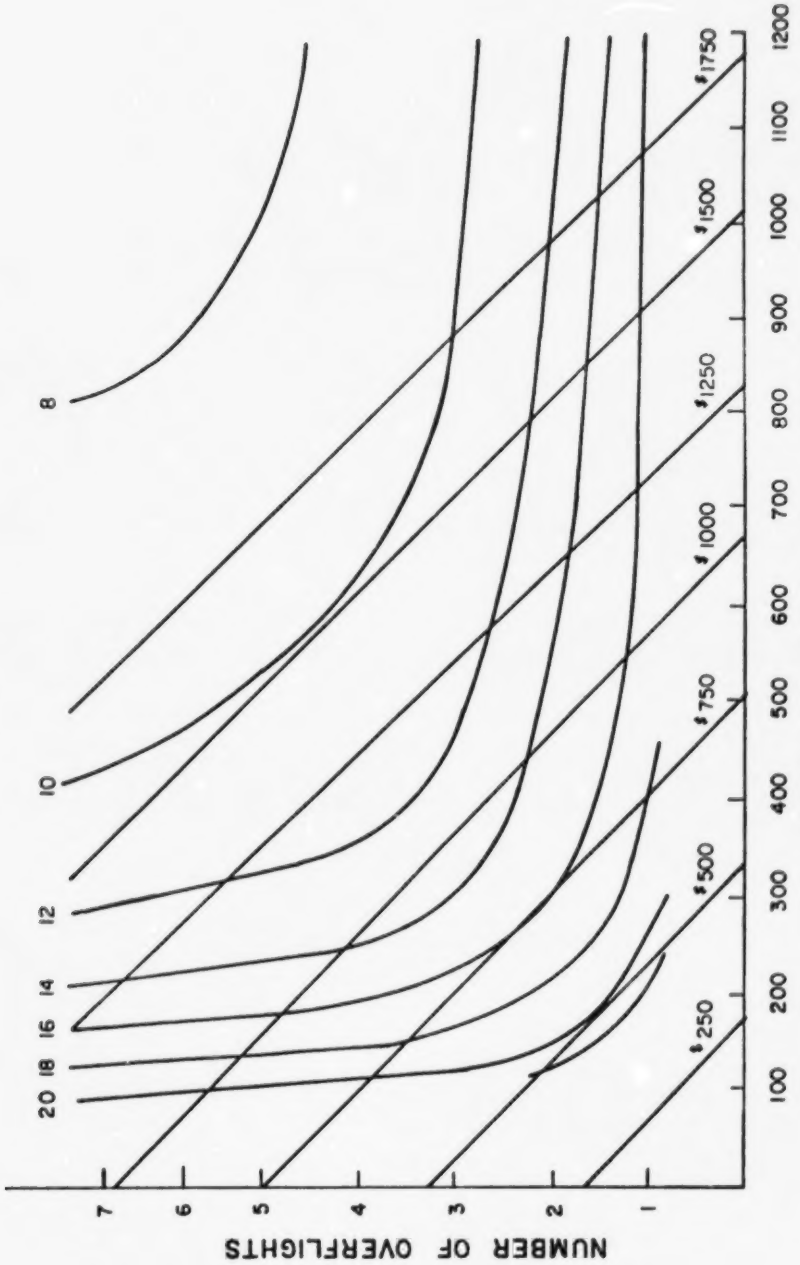


Figure 10. Lines of equal cost superimposed on the nomogram of coefficient of variation of catch (%). (Cost - overflights·$150 + interviews·$1.5).

Mathematical Variance Estimation

The direct mathematical way of estimating the variances of catch and effort involves independently estimating the variances of the components from sample data and then combining these using suitable formulae. There are three components to consider:

1. catch per unit effort - the variance of the estimate of CPE can be calculated as:

$$\frac{VAR(CPE)}{N} \tag{8}$$

where VAR (CPE) was calculated using interview data in the standard variance formula and, N was number of interviews.

2. proportion of boat trips active (P)-assuming a binomial distribution, the variance of P can be calculated as:

$$\frac{P(1-P)}{N} \tag{9}$$

3. overflight counts - due to the small population being sampled, a correction factor must be included to account for lack of replacement:

$$\frac{VAR(OVERFLIGHT\ COUNTS)}{N} \cdot \frac{N-n}{N-1} \tag{10}$$

where VAR(OVERFLIGHT COUNTS) was calculated using overflight data in the standard variance formula, N was the number of like days in a month and n was the number of days sampled.

One component considered in the Monte Carlo analysis that is not included here is the effect of uncertainty in the overflight time.

These three components are then combined using two equations:

$$VAR\left(\frac{X}{Y}\right) = \frac{EX^2}{EY^2}\left\{\frac{VARX}{EX^2} + \frac{VARY}{EY^2}\right\}, \text{ and} \tag{11}$$

$$VAR(XY) = EX^2 \cdot VARY + EY^2 \cdot VARX + VARX \cdot VARY, \tag{12}$$

where VARX represents variance of x, and EX^2 represents the expected value of x^2. Equation 11 (Cochran 1963) is used to combine the overflight counts (X) with the proportion active boats (Y) to obtain the variance of the effort and then Equation 12 (Goodman 1960) is used to include catch per unit effort to give the variance of the catch. Equation 12 is an exact solution while Equation 11 only includes the significant terms of a Taylor series expansion.

Table 8 shows a comparison of the two estimation methods. The two sets of estimates are similar although the Monte Carlo estimates are a little higher due to the inclusion of uncertainty in the overflight timing.

Table 8. A comparison of variance estimates using Monte Carlo simulation and mathematical estimation (see text).

# Overflights	Coefficients of Variation (%)	
	Catch	
	Monte Carlo Estimate	Mathematical Estimate
Victoria, July, weekends		
1	15.7	
3	8.5	14.8
5	6.5	8.0
7	5.7	5.7
		4.4
Nanaimo, March, weekdays		
2	47.1	42.1
	Effort	
2	37.2	36.6

Biases

Following is a discussion of three main biases associated with this type of survey. Due to the structure of the 1980-81 creel survey data, it is not possible to estimate the relative importance of these, although none of them seems likely to have a large effect.

Site and Boat Selection

If there are differences in catch per unit effort or activity pattern between different boat types, then it becomes important to obtain an unbiased sample. In the 1980-81 creel survey, a random sample is taken of all boats landing at a series of sites (primarily ramps where motorized vessels are launched or marinas where large vessels are moored). With this approach, the choice of sites becomes important. Table 9 shows a comparison of the boat types sampled in a 1978 telephone survey and the 1980-81 creel survey. In general, the figures are similar although the creel survey method misses most rowboats, canoes, etc., and favors boats in the 16-31 foot length class. The importance of these differences cannot be assessed without a more detailed analysis of the characteristics of these boat types.

Table 9. Comparison of boats sampled in 1980-81 creel survey and boats used primarily for fishing from a telephone survey.*

	Propulsion Method (%)				Length Class (%)		
	Sail	Outboard	In/In-Outboard	Other	<16'	16-31'	>31'
Telephone Survey	2.1	63.3	23.8	10.6	44.3	50.8	4.9
1980-81 creel survey	2.4	69.0	28.0	0.6	39.7	57.8	2.5

*Resident boating in Georgia Strait, 1979 update, M.C. Harrison.

Correlations Between Activity Pattern and Effort

It is possible that the activity pattern is related to the amount of effort on any given day. For instance, on a fine sunny day with high effort, the curve may be displaced to the right because of an effort response to good weather in the morning which leads to a positive correlation between daily effort and the proportion of boats active in the evening. Since the activity curves are calculated using weights as described above (equation 1), these correlations will not effect the monthly effort estimate.

Coupling Survey Areas with Overflights

One problem with forming a catch estimate for a particular area is that the overflight count must be associated with an activity pattern calculated using data from a subset of the landing sites sampled.

In the 1980-81 survey this linkage was established during the year using information on fishing location obtained from the ramp surveys. However, the anglers fishing in one saltwater statistical area may land at very different sites and contribute to very different activity patterns. In these circumstances the choice of a specific land based activity pattern for each saltwater statistical area becomes very subjective. This problem could be resolved by compiling activity patterns for each fishing area rather than each landing area.

DESIGN CHANGES FOR 1982-83 CREEL SURVEY

The analyses performed on the 1980-81 creel survey data has identified areas where the 1980-81 creel survey design could be improved in terms of costs, precision and accuracy.

Costs were reduced by using Figure 10 to select the most cost effective combination of overflights and interviews. The cost per interview was reduced by selecting the busiest landing sites in each region, since the cost per interview is least at these locations.

The precision and accuracy of the sport fishing effort statistics were increased by:

1. calculating the mean time of the overflight boat count for each sub-statistical area (for all aerial surveys within a month) to within ±one minute;

2. synchronizing the time of the overflight boat count with the peak in sport fishing activity pattern; and

3. systematic mapping landing site statistics to the sub-statistical areas where the fishing took place.

Changes (1) and (2) have removed much of the uncertainty associated with the variance estimate for fishing effort. Figures 11 and 12 show how the timing of the aerial survey was co-ordinated with the peaks in fishing activity patterns for the north and south Georgia Strait, respectively.

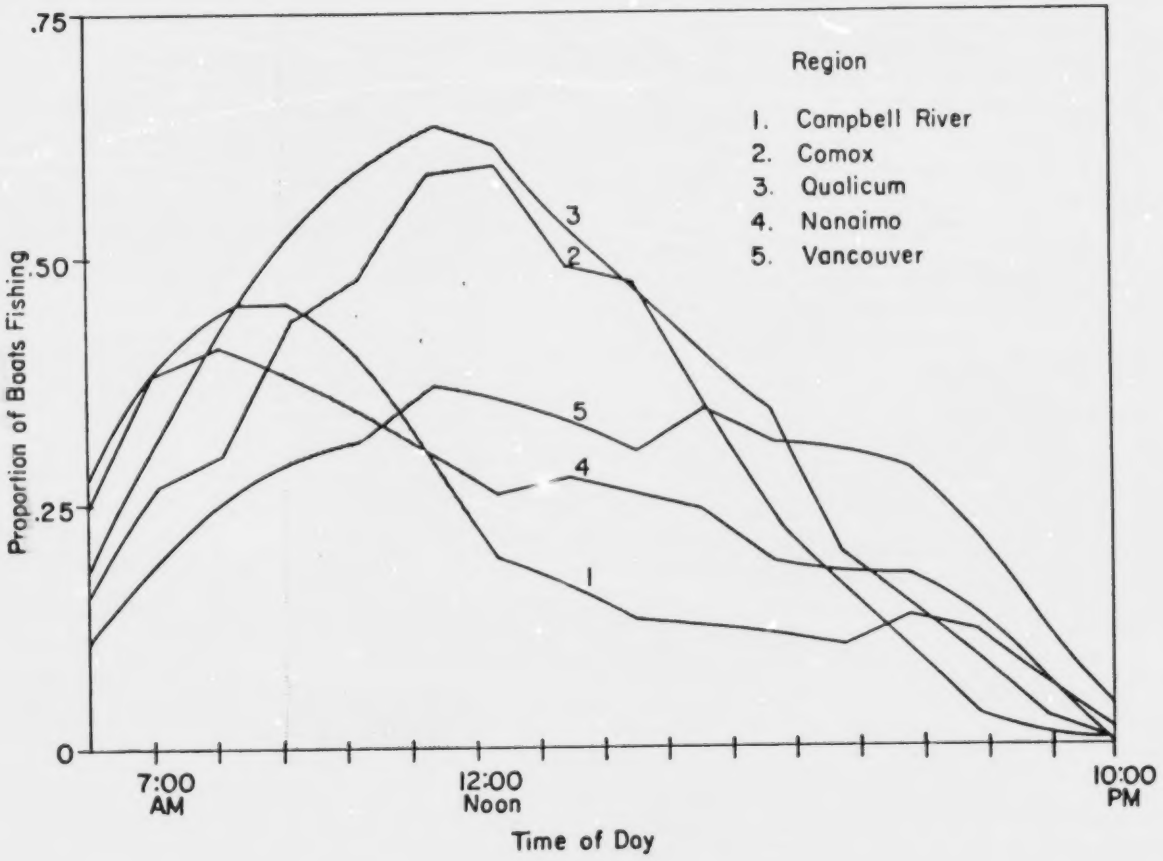


Figure 11. Overflight timing on northern flight path. (The shaded area indicates the timing of overflights for the 1982-83 creel survey while the activity patterns were obtained from 1980-81 data.)

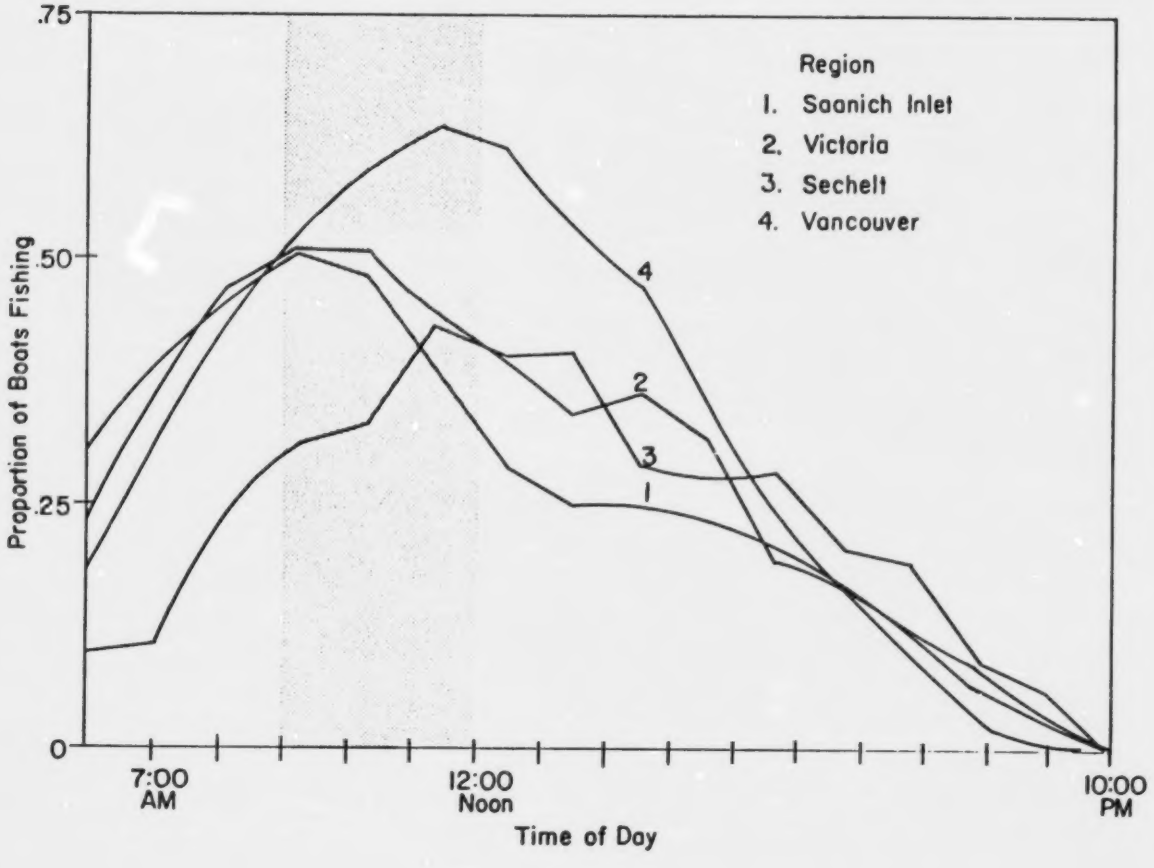


Figure 12. Overflight timing on southern flight path. (The shaded area indicates the timing of overflights for the 1982-83 creel survey while the activity patterns were obtained from 1980-81 data.)

The mapping of landing site to fishing areas insured that catch per effort figures were combined with the appropriate effort figures for an estimate of total catch. This analysis has also revealed the degree to which the interviews cover all fishing areas. According to summer and winter statistics from 1982, landing site interviews sample sport fishing in 85% of the sub-areas in Georgia Strait representing at least 94% of the effort (Table 11). The accuracy of catch statistics would not be affected unless unsampled CPE was consistently higher or lower than sampled CPE (from adjacent areas) and unsampled sub-areas contained a significant portion of total effort. Given the normally large variance in CPE and relatively small amount of effort involved, missed areas would not significantly affect the accuracy of total sport catch statistics for Georgia Strait.

Table 10. Portion of Georgia Strait sport fishing areas and effort not represented in 1982 interview data.

	Sub-Areas Missed*			Effort** in		
Month	No.	Total	%	Sub-Areas Missed*	All Areas	%
July	5	59	9	85	3,306	3.6
August	8	59	14	216	3,703	5.8
November - December	9	59	15	21	371	5.7

* Missed areas are areas where boats were counted but no interviewees reported fishing in that area.
** Mean effort estimates derived from aerial surveys of Georgia Strait during each period.

FUTURE CREEL SURVEYS

The 1980 through 1983 creel surveys were designed to provide monthly statistics for sport catch and effort in Georgia Strait. During 1983, monthly statistics were available within two weeks of the end of each month. The future prospect of sport fishing quotas will require catch estimates at this frequency or better.

Current sampling effort would be sufficient to provide weekly or bi-monthly bench mark vessel counts and catch per effort statistics; however, most weeks would require many more interviews to be confident of the constructed activity patterns. An alternative to the added expense of more interviews would be to use the activity patterns for the appropriate month and statistical areas from previous years. The utility of this approach can be evaluated through an examination of year-to-year variability in activity patterns.

Activity Pattern Analysis

The effect of year-to-year variability in activity pattern on the effort estimate was assessed by using 1980, 1981 and 1982 activity patterns, with

1982 overflight data, to calculate 1982 effort. Comparisons of effort estimates were stratified by month and statistical area. Significant differences between effort estimates were identified by examining the 95% confidence limits around comparable estimates.

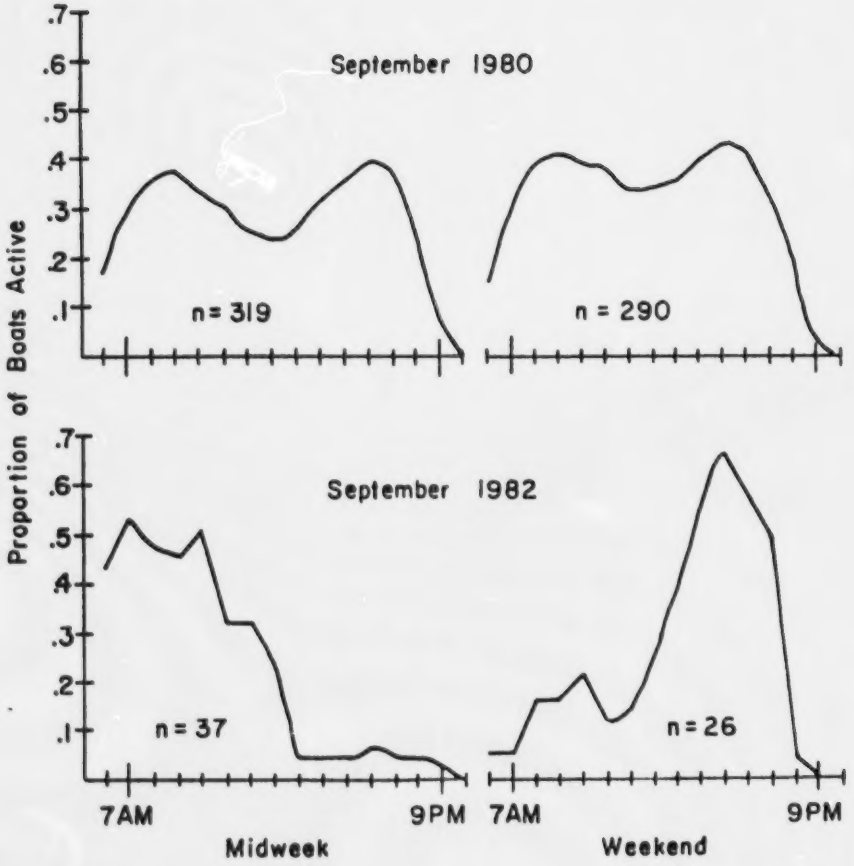
Of 135 comparisons only 3 were significantly different ($P < 0.05$). However, there are several factors which influence the detectability of differences in the effort estimate. The detectability of significant differences is largely determined by the precision of the effort estimate (expressed by the 95% confidence interval), which in turn is dependent on the following factors:

1. the proportion of boats active during the time of the overflight boat count;
2. the number of interviews contributing to the activity pattern; and
3. the variability associated with the overflight boat counts.

If close to 50% of the boats are active at the time of the overflight, the number of interviews is small (less than 50) and/or the variability in the overflight boat counts is high; very different activity patterns may not produce statistically different effort estimates (Figure 13). Also, because of spatial and temporal stratification several activity patterns may be involved to produce one effort estimate. All these factors reduce the sensitivity of the effort estimate to changes in activity patterns. Figures 14a and 14b shows the activity patterns responsible for the three significant different effort estimates found in this analysis. These results lead to the conclusion that while activity patterns may have changed over the past three years they have not significantly affected most effort estimates. Therefore, activity patterns from the previous year are certainly adequate for the weekly or bi-monthly effort estimates that may be required in the future. However, activity pattern data should be collected each year. Since interviews must be conducted to obtain catch per effort data, activity pattern data could be collected at no additional cost and used to verify or correct the in-season weekly estimates at the end of each month.

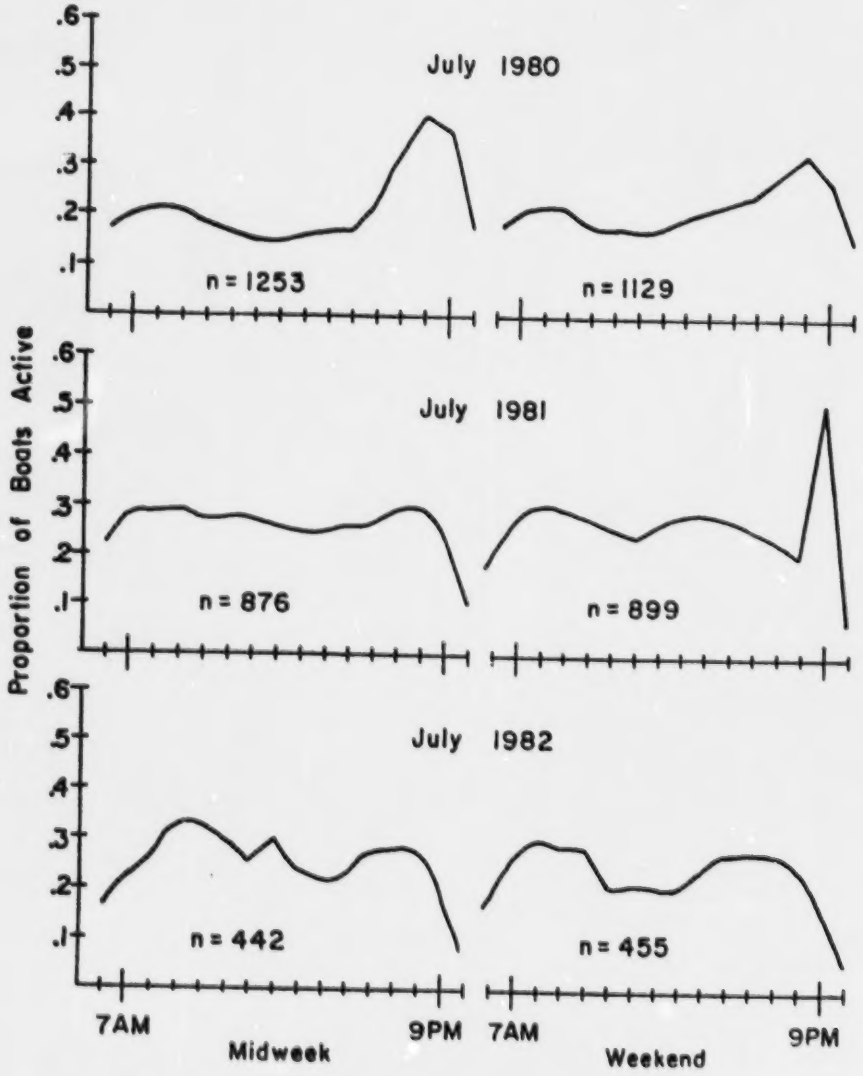
Mapping Analysis

The comparison of aerial survey boat counts with interview data has identified how interview effort should be redistributed for future creel surveys. In general the number of interviews representing a sub-statistical area should be proportional to the mean effort estimate for that area. In five regions representing 15 sub-statistical areas the number of interviews were disproportionately distributed (Table 11). In summer, some of the interview effort expended in north Comox should be redistributed to the northern Sechelt, Nanaimo, the southern Gulf Islands and Howe Sound. In winter, some of the interview efforts expended near Nanaimo should be redistributed to northern Sechelt and Howe Sound. While the above changes may improve sub-statistical area statistics, they would not significantly alter total figures.



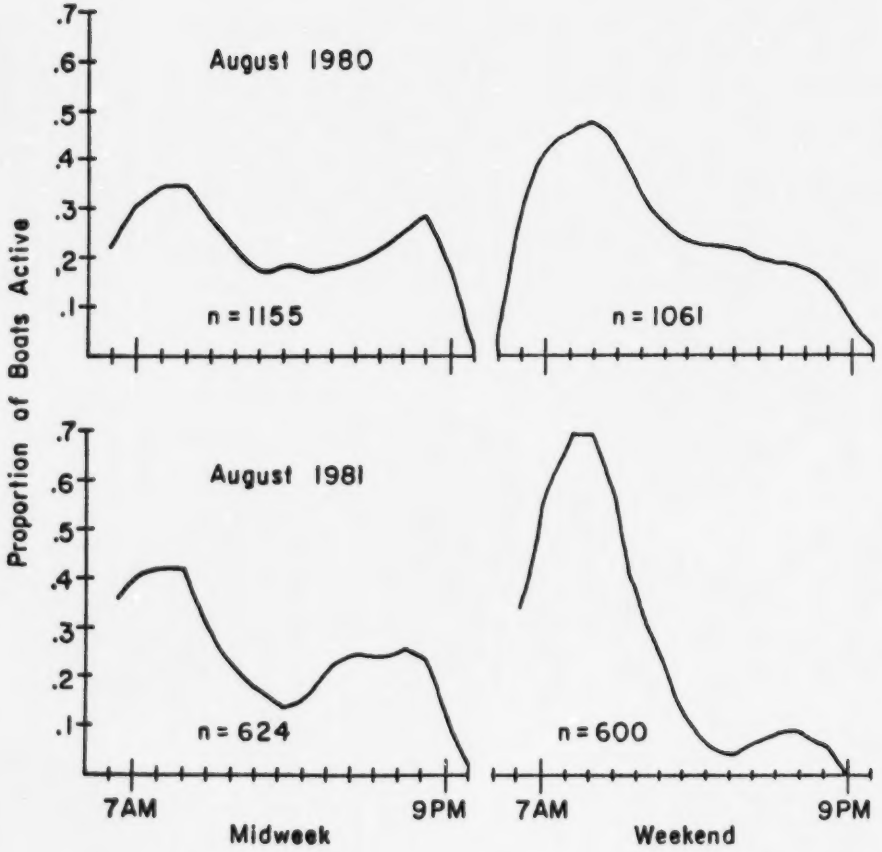
1982 Effort Estimate	95% Confidence Interval
14,113	11,013 - 17,213
23,903	12,877 - 34,929

Figure 13. Example of different activity patterns which did not produce statistically different ($P > .05$) effort estimates. Boat counts from September 1982 aerial surveys were used with each activity pattern to estimate effort Statistical Area 13. (n - number of interviews).



1982 Effort Estimate	95% Confidence Interval
47,923	42,417 - 53,429
33,553	29,757 - 37,349
32,104	28,236 - 35,972

Figure 14a. Activity patterns which produced statistically different ($P < .05$) effort estimates for Statistical Area 13 (n = number of interviews).



1982 Effort Estimate	95% Confidence Interval
25,023	22,081 - 27,965
18,823	16,601 - 21,045

Figure 14b. Activity patterns which produced statistically different ($P < .05$) effort estimates for Statistical Area 19 (n = number of interviews).

Table 11. Regions where the number of interviews are disproportionately distributed; sub-statistical areas in brackets.

Location	July		August		Nov. - Dec.	
	% Effort	% Interview	% Effort	% Interview	% Effort	% Interview
1. Comox (NE) (13A,14J,14K,15A)	12%	27%	10%	19%	1%	1%
2. Sechelt (N) (16A,16B)	6%	2%	7%	1%	6%	1%
3. Nanaimo (17D,17E,17F,17G)	6%	<1%	5%	<1%	3%	16%
4. Gulf Islands (S) (18C, 18D)	4%	<1%	4%	0%	1%	0%
5. Howe Sound (28A,28C,28D)	14%	10%	14%	6%	30%	11%

% Interview = number of interviews where fishermen reported fishing in the region divided by the total number of interviews for that month.
% Effort = mean effort estimate for the region divided by the total effort estimate for that month, from aerial survey data.

1980-83 CATCH AND EFFORT STATISTICS

All of the data gathered in the 1980-1981 DPA creel survey and subsequent Department of Fisheries and Oceans (DFO) creel surveys and aerial surveys are available on the Pacific Biological Station VAX 360 computer. In 1982, computer programs were written to analyse the DPA 1980-1981 creel survey data. In February of 1983 these programs were modified and used to compute catch and effort statistics for the 1982-1983 creel survey conducted by DFO. A complete documentation of these analysis programs has been prepared (English 1983).

Unfortunately, the creel survey has not been continuously conducted since its inception in July 1980 (see Table 1). No landing site surveys were conducted from September 1981 through April 1982, while aerial surveys were conducted during some of these months. For the three months without aerial or ramp survey data (September 1981, October 1981 and April 1982) estimates were obtained by averaging catch and effort from the appropriate months in previous and subsequent years. During the remaining months (November 1981 through March 1982) spot counts of effort from aerial surveys were conducted. These spot counts were combined with catch per effort and activity pattern data from the appropriate months in the previous and subsequent years, producing two estimates for each month in the above period. These two estimates were averaged to produce the final estimate.

It was recognized that changes in stock strength, weather, sport fishery regulations and opportunities to sport fish resulting from economic conditions

will affect sport catch and effort. The averaging procedure described above gives equal weight to each estimate irrespective of the above factors.

The 1980-83 data plotted in Figures 15 and 16 show both within and between year variability in sport fishing effort and chinook catch statistics. Each year shows a similar pattern for sport effort; rapid increases in May and June, peaks in July or August and sharp declines in September and October. However, sport fishing effort was much lower in July - August 1983 than it was in July and August of the previous 3 years. Chinook catch statistics show the most dramatic changes over the past 4 years (Figure 16). Until June 1983 chinook catches had shown consistent reduction for each month in successive years. June 1983 chinook catch surpassed June 1982 catches; by August 1983 catches were approaching 1981 levels, and September 1983 marked the highest September chinook catch of the past 4 years. Chinook catch per effort showed a sustained increase throughout the summer months when CPE has declined or remained constant in previous years (Figure 17). The following section attempts to unravel the causes for these dramatic changes in chinook catch statistics.

EXPLANATION OF TRENDS IN CHINOOK CATCH STATISTICS

From July 1980 to October 1983 there were marked changes in the seasonal and annual chinook catch per effort for the Georgia Strait Sport Fishery (Table 12). The two most likely causes for these major changes in CPE are:

1) changes in chinook stock strength and/or
2) recent changes in sport fishery regulations.

Differentiation between the two factors is an important issue because of the implications for future fishery management.

Since June 1982 there have been eight changes in the Georgia Strait tidal sport fishery regulations (Table 13). Regulations pertaining to lines per boat, downriggers, weight restrictions and spot closures probably had little or no effect on chinook CPE. Of the three regulations specifically implemented to reduce chinook catch (a new daily bag limit, an annual bag limit and a new minimum size limit), the new size limit was likely the only regulation which had a significant effect on chinook CPE.

1) Lines per boat

The average number of lines per sport boat trip was 2.1 (DPA 1982) prior to the introduction of the new regulation. The average number of lines per boat estimated by the Georgia Strait creel survey subsequent to the regulation is 2.08. Therefore, changes in CPE have not resulted from this regulation.

2) Downriggers and weight restrictions

The new requirements for a quick release mechanism on downriggers and maximum weight for fishing lines were intended primarily to preserve a sporting quality when angling rather than to reduce angling efficiency. Furthermore most anglers used quick release mechanisms with downriggers prior to the new requirement. CPE changes are therefore not expected as a result of a requirement for quick release mechanisms.

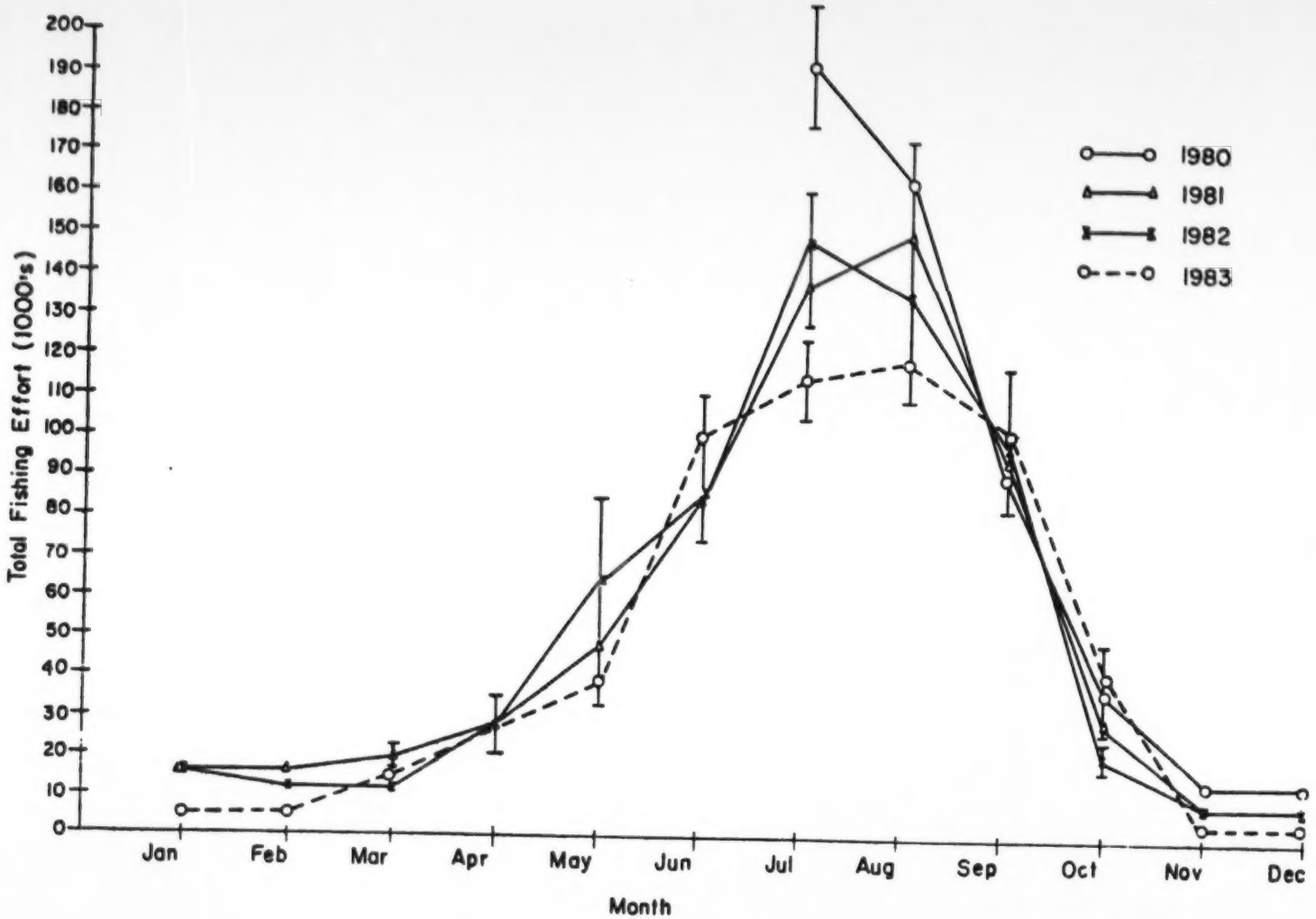


Figure 15. Monthly effort estimates for the Georgia Strait sport fishery, July 1980 - December 1983.

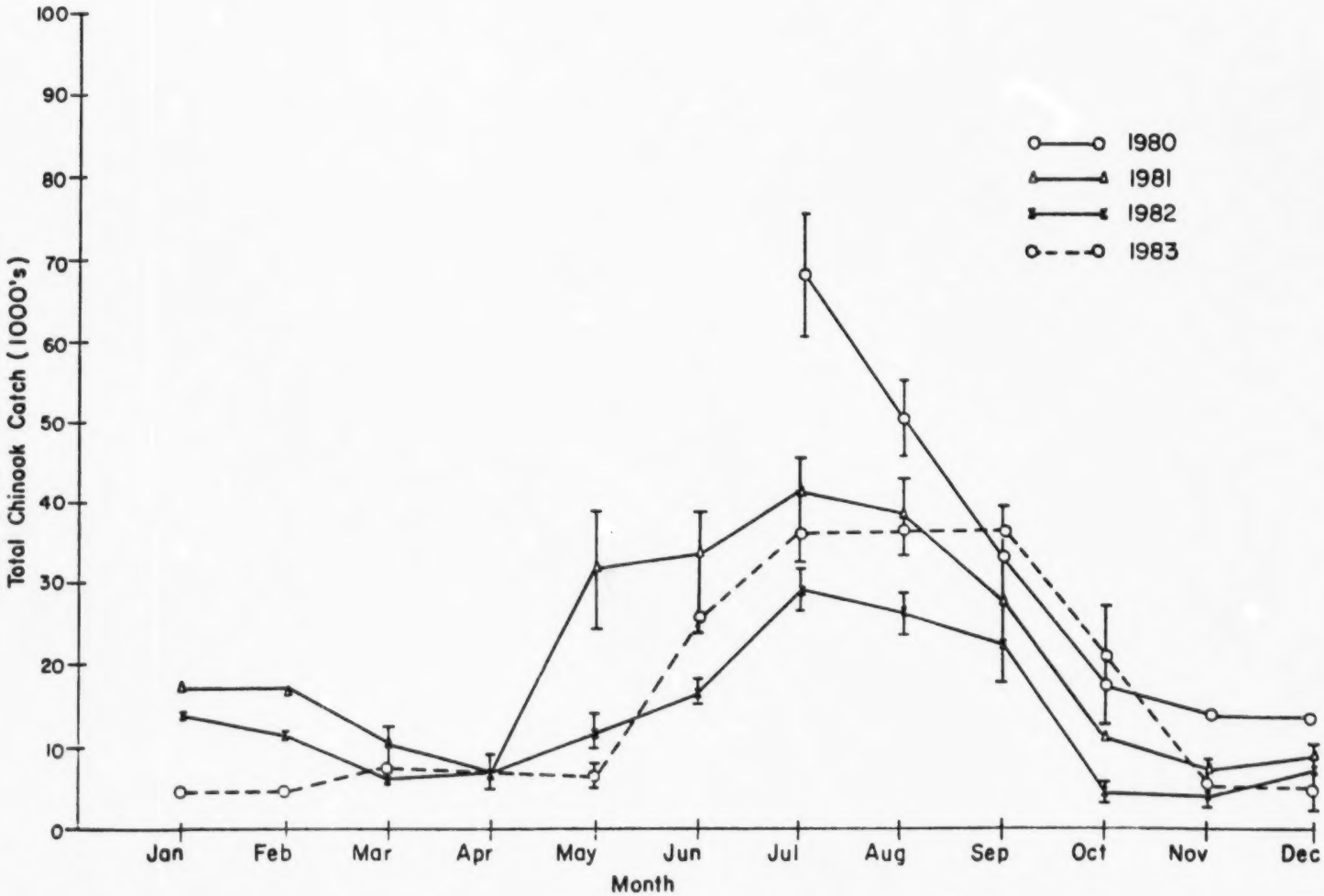


Figure 16. Monthly chinook catch estimates for the Georgia Strait sport fishery, July 1980 - December 1983.

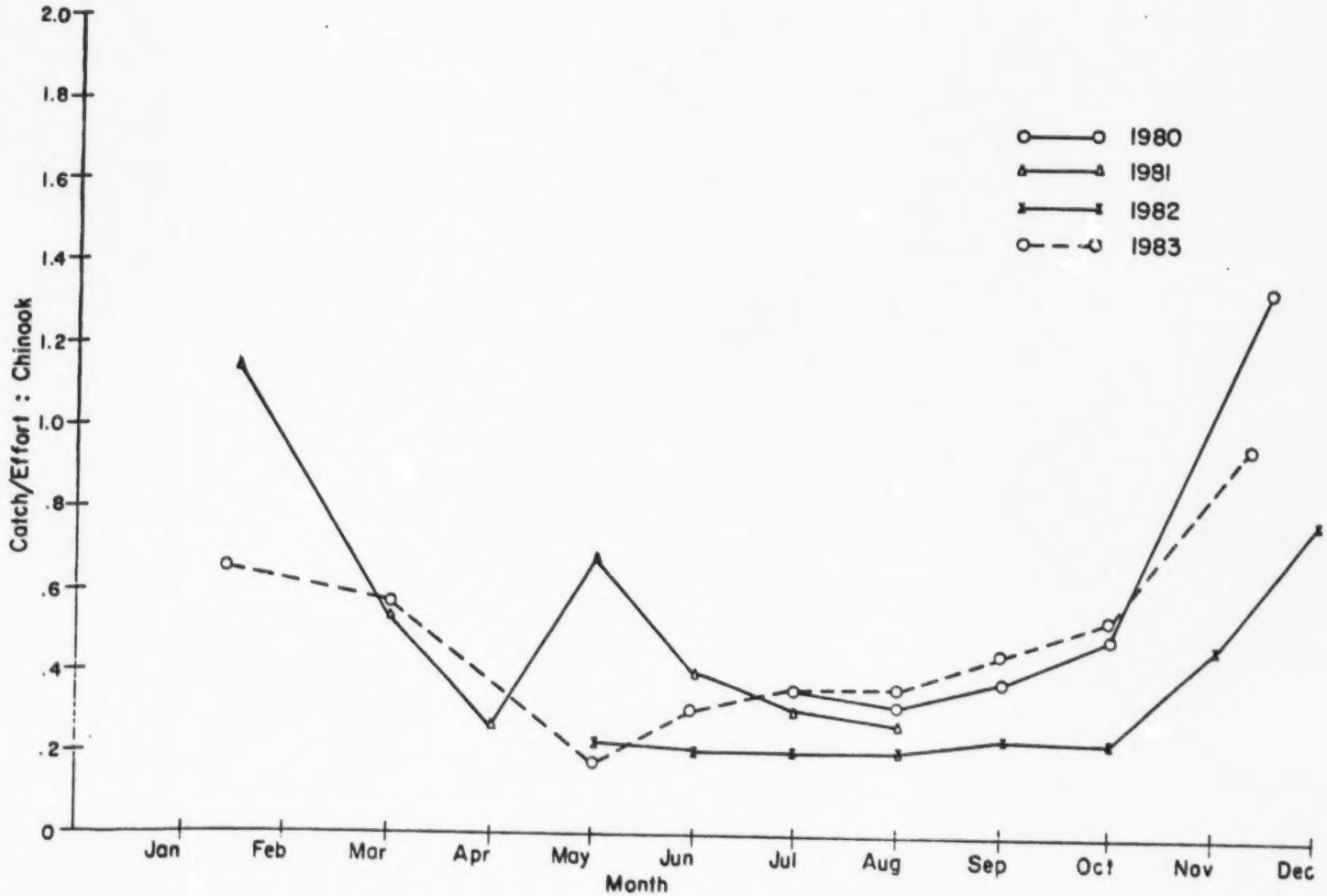


Figure 17. Chinook catch per boat trip for months when creel surveys were conducted throughout Georgia Strait.

Table 12. Seasonal and annual changes in chinook catch and catch per effort statistics for the Georgia Strait sport fishery, 1980-83.

	Whole Year			July and August		
	Catch (x1000)	CPE	% Change in CPE	Catch (x1000)	CPE	% Change in CPE
1980*	324	.45		118	.33	
1981	257	.40	-11	81	.28	-15
1982	173	.26	-35	57	.20	-29
1983	198	.35	+33	75	.32	+60

* (Estimate for 1980 survey year was obtained by adding the 1981 first-half estimate to the 1980 last-half estimate.)

Table 13. Changes in tidal sport fishing regulations after June 1981.

	Pre- June '81 Regulations	Regulation Changes	Month/ Year
Size limits	30 cm minimum for all salmon	30 cm minimum for all salmon except 45 cm minimum for chinook	Jun/81
Bag limits	4 salmon/day any species	4 salmon/day any species except from Dec. 1 - March 31 when only 2 of 4 may be chinook	Jun/81
Licences	None required for tidal water fishing	Required in tidal waters	Jun/81
Lines per boat	No limit	No limit unless a person in boat is under 16 or is unlicensed then only one line per angler	Jun/81
Downriggers	No specific restrictions	Must be used with quick release mechanism	Jun/81
Closures	None - except in small area (e.g., Nanaimo estuary)	Spot closures in small area (e.g., Saanich Inlet October & November 1981)	Oct/81
Weight Restrictions	None	Max. 1 kilo weight fixed to fishing lines	Apr/82
Annual Bag Limit	None	30 chinook per angler	Apr/82

3) Spot Closures

The closures used since 1980 have been very localized and infrequent. Small areas such as the Nanaimo River estuary and portions of Saanich Inlet were briefly closed to angling. These closures should not affect total CPE.

4) Winter Daily Bag Limit

The impact of the 2 chinook bag limit between December 1 and March 31 was assessed using 1980 - 82 creel survey data. The distribution of bags from the 1980-81 creel survey (Table 14) shows that only 3% of fishermen reached a 2 salmonid bag limit (given a mean party size of 2.3 anglers per boat).

Data from the 1980-81 survey has shown that the frequency of bags of various sizes follows a negative binomial distribution (see Bias and Variances section). Using this information, it is possible to calculate the reduction in sports catch for various bag limits with various levels of catch per boat trip. Figure 18 shows this information in nomogram form using the catch per boat trip experienced with no bag limit[1]. A number of assumptions were used in producing this diagram:

1. a personal bag limit will translate into a limit per boat (personal limit x number licensed fishermen on board);
2. fishermen will not sort their catch;
3. the 1980/81 bag limit had little effect on the shape of the distribution of bags; and
4. there is no behavioural response to the regulation change.

Figure 19 shows the catch per boat trip experienced while the bag limit is in place. Thus with a low bag limit, high catches per boat trip cannot be obtained (legally). This figure can be used to assess the effect of bag limits from data gathered when they are in place. Given that the chinook CPE from December 1 to March 31 is 0.6 - 1.2 fish per boat trip (Figure 19), a reduction in the daily bag limit from 4 to 2 fish per angler or 9.2 to 4.6 fish per boat would suggest a 15% reduction in catch. Since only 20% of total chinook catch occurs in the affected period there would be only a 3% reduction in total chinook catch given the same fishing effort.

5) Annual Bag Limit

The 30 chinook annual bag limit, implemented in April 1982, was intended to reduce chinook harvests by reducing the excessive catch of a small group of very successful anglers. The B.C. Tidal Water Sport Fishing Diary program gathers statistics on the distribution of annual chinook catch per angler. Since 1981, the diary program statistics have been improved by larger sample sizes obtained by randomly selecting individuals from the known population of licensed anglers. (Bijsterveld 1983, Bijsterveld and Moore 1984). In 1981 diary program questionnaires returns indicated that 6.7% of the B.C. resident anglers chinook catch was caught after the individual had personally kept 30 chinook, compared to 0.2% in 1982. (Lia Bijsterveld, Fisheries and Oceans, pers. comm.). In 1981, .95% of the 8501 respondents reported that they caught

[1]Note that the information shown is simply reduction in catch and does not take reallocation into account.

Table 14. Distribution of salmonid catch from Georgia Strait creel survey raw data, all regions, taken from DPA (1981).

Month		No. of Interviews (Boat Trips)	Number of Salmonids per Boat Trip													# of Boat Trips (1) With Limit of Salmonids
			0	1	2	3	4	5	6	7	8	9	10	11	12+	
July	1980	12,517	49.6	19.0	11.1	7.1	5.0	2.3	1.9	1.3	1.7	.2	.2	.1	.5	2.4
August	1980	10,199	55.5	20.4	10.4	5.6	3.7	1.4	1.1	.6	.8	.1	.1	.1	.2	1.5
September	1980	3,337	54.2	21.3	10.6	5.8	3.4	2.0	1.1	.5	.6	.1	.1	-	.3	1.3
October	1980	2,129	57.6	19.1	10.1	5.2	3.6	1.5	1.0	.6	.9	.1	.1	.1	.1	2.2
November	1980	533	50.8	18.6	8.8	7.5	6.2	2.8	.9	.2	3.2	-	.6	-	.4	5.8
December	1980	407	42.8	17.2	13.5	10.8	7.9	2.7	1.5	1.2	2.0	.2	.2	-	-	6.4
January	1981	1,123	47.5	16.5	10.9	8.4	7.6	2.5	1.8	1.1	2.9	.1	-	.2	.5	5.9
February	1981	945	52.7	18.6	9.7	8.6	4.1	1.6	1.4	.6	1.9	.1	-	.1	.6	3.8
March	1981	805	60.6	15.4	10.3	4.7	4.7	1.7	.6	.4	1.0	.4	-	.1	.1	3.0
April	1981	733	61.6	17.5	10.2	4.8	2.7	1.8	.5	.4	-	-	.1	-	.4	.8
May	1981	3,387	48.6	19.0	11.6	7.5	5.5	2.3	1.9	.6	2.3	.3	.1	-	.3	3.7
June	1981	4,720	49.3	19.2	11.0	6.0	5.6	2.2	1.7	1.4	2.2	.3	.3	.2	.6	3.9
TOTAL		40,835	52.1	19.4	10.8	6.5	4.6	2.0	1.5	.9	1.5	.2	.1	-	.4	2.5

(1) Refers to # of boat trips where the number of salmonids in creel was equal to or greater than four per person.

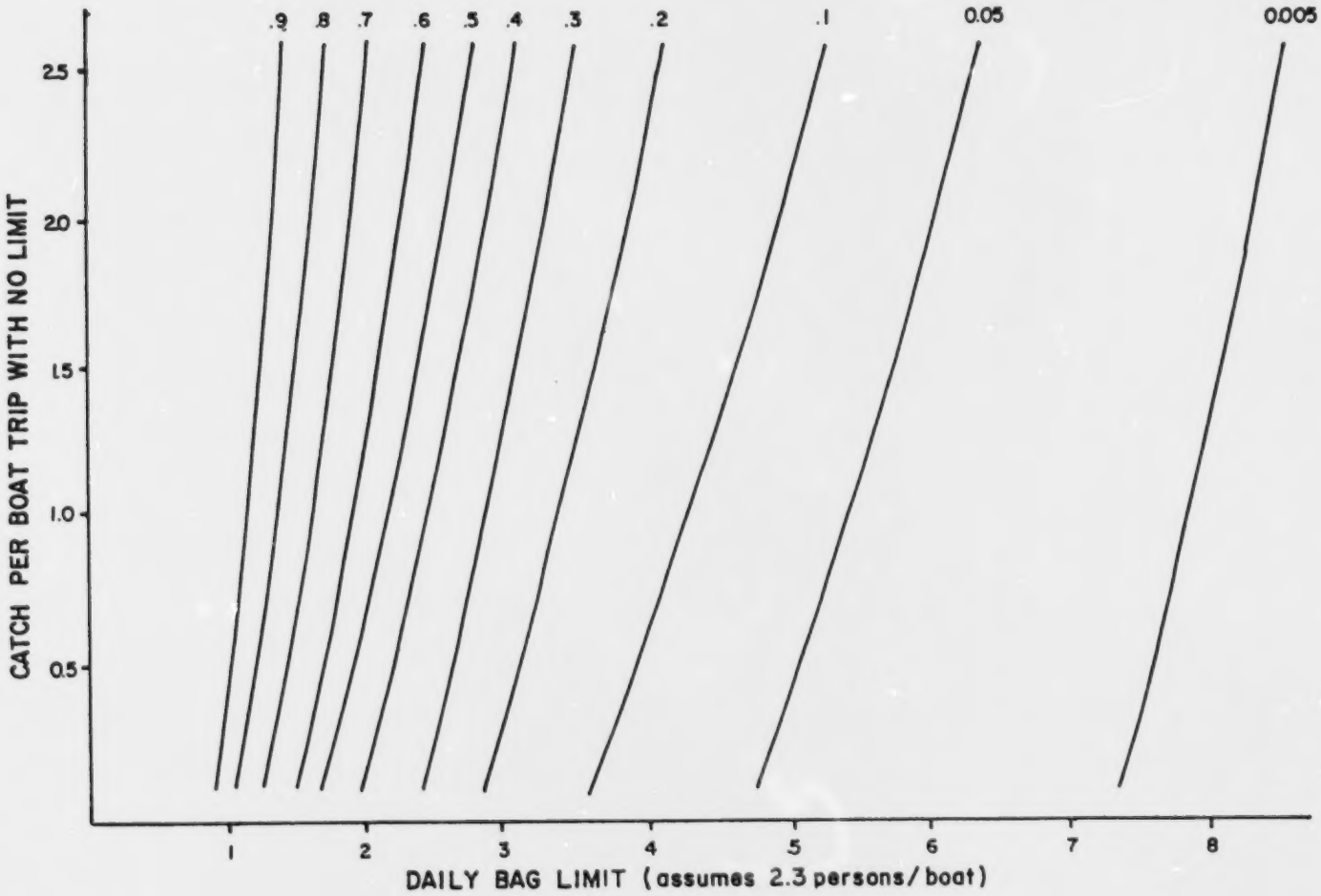


Figure 18. Proportionate reduction in catch for daily bag limits at various catch per unit effort levels.

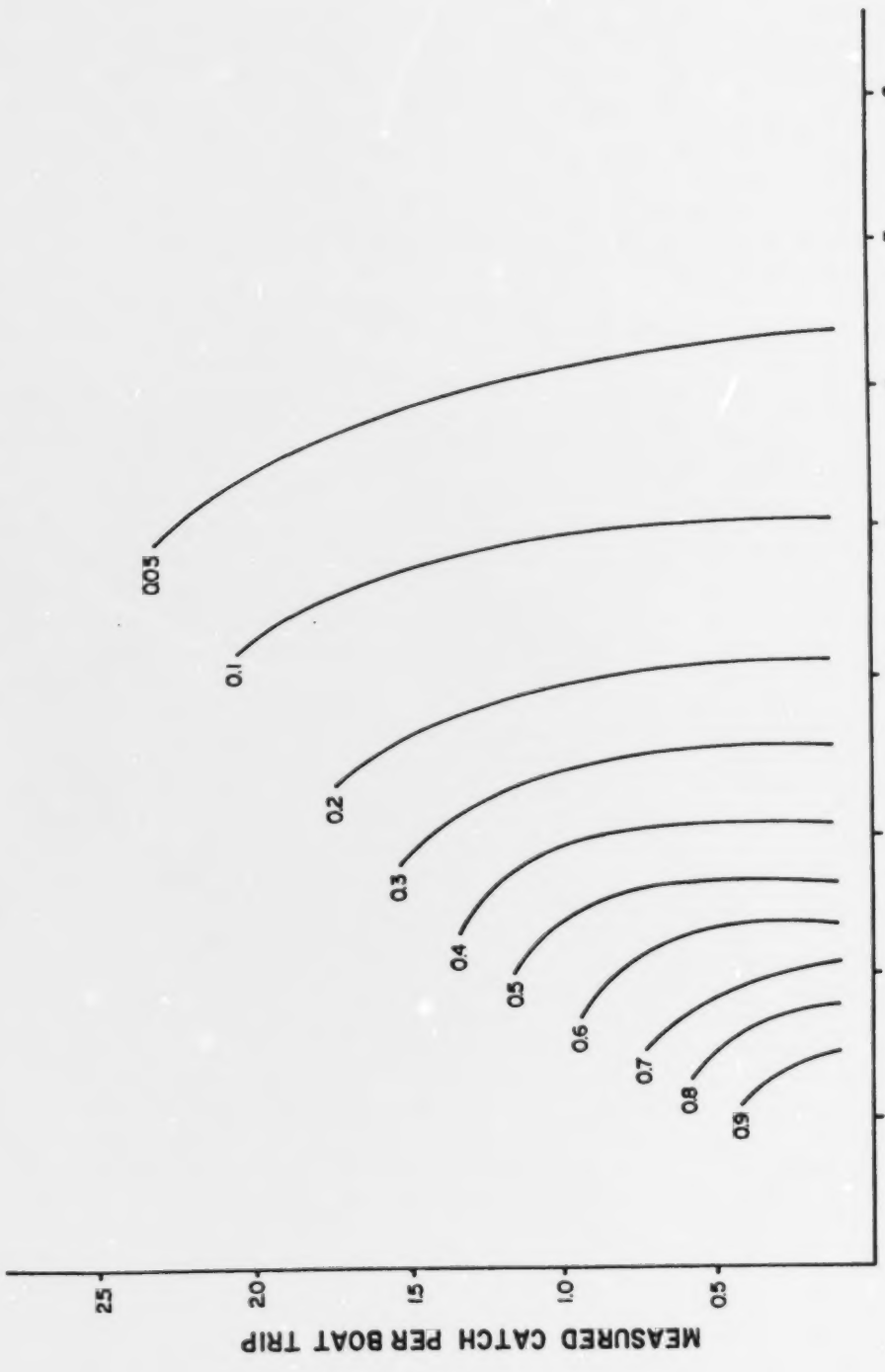


Figure 19. Proportionate reduction in catch for daily bag limit at measured catch per unit effort levels.

more than 30 chinook, compared to .05% of 6068 respondents in 1982. If these statistics represent comparable chinook catch rates the maximum reduction in chinook harvest due to the annual chinook bag limit would be 6.5%. However, the same catch could be spread over more individuals or individuals without a 30 chinook annual limit (anglers under 16 years of age) without any change in overall harvest rate. In addition, there is a strong tendency for individuals not to report illegal catches, thereby exaggerating the significance of a bag limit regulation.

6) Size Limit

The only new regulation which could significantly affect 1981 chinook CPE was the increase in the minimum size limit effective July 1981. The impact of the 45 cm (18 inch) size limit regulation on chinook CPE was examined using a cohort analysis for chinook caught in the Strait of Georgia fisheries. The analysis reconstructs a chinook cohort using catch at age and escapement data along with mortality rates, emigration and immigration parameters. Once the cohort has been reconstructed, the effect of different regulations on chinook catch by age and harvest rates by brood year can be estimated. A detailed description of this cohort analysis can be found in Argue et al. (1983) and English and Hilborn (1981).

The cohort analysis was set up to simulate the 1981 sport and troll catch statistics, with the 1981 sport minimum size limit of 30 cm (12 inches) until June 30, and 45 cm (18 inches) starting July 1. The cohort analysis uses historical catch at age and size distribution data to partition monthly sport and troll catches into catch by age class. The size distribution data is used to calculate the proportion of each age class that is larger than the minimum legal size in each month. Since 30-45 cm size limits only affect the recruitment of age 2 chinooks to the fishery, any reduction in catch will be shown as a reduction in the number of age 2 chinook caught. Table 15 shows that the cohort analysis would predict a reduction in the 1981 age 2 chinook catch of 71,000 pieces. The actual reduction in total estimated chinook catch July - December 1981 compared with July - December 1980 was 67,000 pieces. Therefore, the observed actual reduction in a catch can be explained by the effect of the new size limit. The 1981 chinook CPE if the 18 inch size limit had not been in effect would have been 0.51 chinook per boat trip based on the cohort analysis. Since the CPE in 1980 was 0.45 chinook per boat trip, this analysis suggests there would have been a 13% increase in chinook sport CPE between 1980 and 1981. It is interesting to note that Georgia Strait commercial troll statistics show an 18% increase in chinook CPE between 1980 and 1981 and no size limit changes were made to the troll fishery. The cohort analysis was also used to determine what additional reduction in chinook catch in the years after 1981 would result from an annual 45 cm (18 inch) minimum size limit. The analysis suggests that, unlike 1980-81, the 1982 regulation change can only account for 11,000 of the estimated 84,000 decrease in chinook catch between 1981 and 1982 (Table 16).

7) Summary

Whereas the new regulations can explain the reduction in catch from 1980 to 1981, they cannot account for the large decrease in 1982 chinook CPE or the subsequent increase in 1983 CPE (Table 12). These changes are probably attributable to changes in stock abundance. If stock abundance was the major factor determining catch, one would expect to see similar trends for both sport and troll chinook catches in Georgia Strait.

Table 15. Difference between predicted and estimated creel survey ~~estimated~~ chinook catch for years with different minimum size limit regulations (1980-1981). (Cohort analysis is based on 1981 effort and catchability coefficients.)

	Cohort Analysis		Total
	Age 2 Catch	Total Catch	Total Catch Estimated
30 cm. whole year	162,000	321,000	324,000 (1980-81)
45 cm. starting July 1	91,000	252,000	257,000 (1981)
Difference	71,000	69,000*	67,000

*total catch is less than age 2 catch because the cohort analysis allows fish not caught as age 2 to be caught later.

Table 16. Difference between predicted and estimated chinook catch for years with different minimum size limit regulations (1981-1982). (Cohort analysis is based on 1981 effort and catchability coefficients.)

	Cohort Analysis		Creel Survey
	Age 2 Catch	Total Catch	Total Catch Estimated
45 cm. starting July 1	91,000	252,000	257,000 (1981)
45 cm. whole year	80,000	239,000	173,000 (1982)
Difference	11,000	13,000	84,000

Comparison of Sport and Troll Statistics

The 1980 - 1982 commercial troll fishery in Georgia Strait shows similar trends in CPE and total catch to those occurring in the sport fishery after adjustments are made for changes in sport fishing regulations (Table 17). However, in 1983 sport chinook CPE increased while troll chinook CPE decreased. This anomaly can be explained by the following facts:

1) a large portion of the Georgia Strait troll chinook catch is normally age 3 fish (77% in 1982, Table 18);
2) troll chinook minimum size limits in Georgia Strait were increased in August 1983 from 45 cm to 58 cm, reducing their catch of age 2 fish to zero;
3) Age composition data from the sport fishery show a significant increase in the catch of age 2 fish between July 1982 and July 1983 (Table 19); and
4) The weak cohort of age 2 chinook in 1982 would be age 3 in 1983.

These points suggest that 1983 sport chinook catch increased because of a strong recruitment of age 2 fish (to the greater than 45 cm size class) while the commercial troll catches declined because of a weak cohort of age 3 chinook, and because the trollers cannot benefit from a strong age 2 cohort with a 58 cm minimum size limit.

Interpretation

As described above, chinook CPE statistics suggest major changes in chinook abundance in Georgia Strait between January 1982 and October 1983. Since ages 2 and 3 are the most common age classes in Georgia Strait catches, changes in the abundance of age 2 and 3 chinooks would more severely affect CPE statistics than changes in the abundance of any other age groups. Therefore, the statistics presented in Table 17 probably reflect a moderate increase in age 2 and/or 3 chinook between 1980 and 1981, and a subsequent 25-30% decrease in age 2 and/or 3 chinook. The numbers presented in Table 20 suggest that 115% (42083/36600) of the reduction in July - December chinook catch between 1981 and 1982 can be explained by the reduction in the age 2 chinook catch. Since there was a less than 1% change in effort during the same period, this analysis suggests at least a 50% reduction in the age 2 chinook cohort between 1981 and 1982.

In 1983 this weak cohort, then age 3 fish, appears to have been responsible for the disproportionate decline in commercial troll catches in Georgia Strait. The 1983 Georgia Strait troll chinook catch was only 48% of the 1981-82 average catch while other Canadian troll fisheries harvested 90% of their 1981-82 average catch. The consistent and substantial increase in Georgia Strait sport chinook catch from June through September 1983 coincides exactly with the recruitment period for a new healthy age 2 cohort, and further identifies the extent of the failure of the 1980 brood year for Georgia Strait chinook stocks.

Problems in west coast hatcheries may be largely responsible for the weak 1982 age 2 cohort (1981 smolts of the 1980 brood stock). In 1981 salmon hatcheries in Georgia Strait and Puget Sound released millions of chinook smolts with severely-impaired vision, due to a dietary deficiency. These smolts probably experienced mortality rates several times greater than those

Table 17. Comparison of sport and commercial troll chinook catch and effort (in thousands) for Georgia Strait 1980-83.

	TROLL**			SPORT				
	Catch	Effort	CPE	Catch		Effort	CPE	
				Observed	Adjusted*	Observed	Observed	Adjusted*
1980	285	31	9.2	324	324	724	.45	.45
1981	252	23	10.9	257	328	645	.40	.51
1982	190	25	7.6	173	255	669	.26	.38
1983	106	20	5.4	198	280	574	.35	.49

PERCENT CHANGE IN CPE			
	Troll	Sport	
		Observed	Adjusted*
80-81	+18	-11	+13
81-82	-30	-35	-25
82-83	-29	+33	+28

* The cohort analysis was used to adjust observed creel survey estimates for changes in chinook minimum size limit regulations. Adjusted values represent relative catches for 1980 sport fishing regulations.

**Sales slip catch and effort; effort is in boat-days.

Table 18. Age composition of annual Georgia Strait sport and troll chinook catches for 1982.

Age	Troll*		Sport*	
	%	95% Confidence Interval	%	95% Confidence Interval
2	6	5 - 7	27	24 - 30
3	77	75 - 79	51	48 - 54
4	15	13 - 17	20	17 - 23
5+	2	0 - 3	2	0 - 3

* estimates weighted for catch
** 95% confidence interval calculated using $\pm 2 \cdot \sqrt{\frac{p \cdot q}{n}}$; assumes no variance in catch estimate (Troll n = 2158, Sport n = 1066).

Table 19. Age composition of sport chinook catch in July 1982 and July 1983.

Age	July 1982			July 1983		
	Sample Size	%	95% Confidence Interval	Sample Size	%	95% Confidence Interval
2	72	29	23 - 35	97	50	42 - 57
3	115	46	40 - 53	52	27	20 - 53
4	52	21	16 - 26	36	18	13 - 24
5	9	4	2 - 7	10	5	2 - 9

Table 20. Comparison of 1981 and 1982 age 2 sport chinook catch statistics for Georgia Strait.

	Age 2 Chinook Catch 1981*	1982**	1981-1982 Change Difference	Percent
July	21,555	8,642	-12,913	-60
August	22,479	10,184	-12,295	-55
September	18,014	12,137	-5,877	-33
October	6,937	2,016	-4,921	-71
November	5,373	2,226	-3,147	-59
December	5,855	2,925	-2,930	-50
Totals				
Age 2	80,213	38,130	-42,083	-52
Effort	421,500	424,000	2,500	< 1
CPE	0.19	0.09	-0.1	-53
All Ages	132,600	96,000	-36,600	-28

* Estimates made using creel survey data in cohort analysis.
** Estimates made using creel survey catch and age data.

released in previous and subsequent years. Mace (1982) found that chinook smolts released from the Big Qualicum hatchery in 1981 experienced 2 - 3 times the 1980 mortality due to bird predation alone. Others have estimated, based on visual examination of chinook eyes, that only 25 - 30% of Georgia Strait and Puget Sound chinook hatchery released were affected (Ted Perry, Canadian Department of Fisheries and Oceans, pers. comm.). Recent analyses of Puget Sound data suggest that only 4 - 5% of Puget Sound hatchery chinooks were affected (M. Fraidenburg, Washington Department of Fisheries, pers. comm.). Further analysis of age 2 catches, hatchery returns and data derived from visual examinations of chinook smolts prior to release may help determine the degree to which the dietary deficiency affected the survival of chinook smolts released from hatcheries in 1981. While the magnitude is in doubt, the 1981-83 catch trends suggest that hatchery chinooks may comprise a dangerously large portion of total chinook population in Georgia Strait.

CONCLUSIONS

Several researchers have evaluated and recommended on site creel survey procedures as the best method for obtaining reliable data on sport fishing catches and catch per effort (English et al. 1982; Hiett and Ghosh 1977). The 1980-83 Georgia Strait Creel Surveys have provided the longest time series of reliable creel survey catch and effort data ever collected for a salmon sport fishery. Detailed statistical analyses conducted on the creel survey data have identified the levels of survey effort required for accurate sport fishery statistics with a known level of precision. These analyses have been used to improve the 1982 and 1983 surveys and evaluate the effect of future changes to survey design. The surveys were designed to detect and respond to

seasonal and annual changes in the distribution of fishing effort. The aerial surveys provide an independent estimate of the distribution of fishing effort with which managers can monitor the coverage of interview data. The large number of angler interviews sample fishing effort in most areas of Georgia Strait throughout the year. The program, designed to provide the data needed for accurate estimates of sport catch and effort, also provides reliable data for assessing changes in chinook and coho abundance in Georgia Strait.

Analyses presented in this report identify major changes in chinook catch per effort which can be attributed to changes in the abundance of specific cohorts. Although changes in minimum sport size limit affected catches in 1981, stock strength seems to be the primary factor determining sport catches. The partial failure of a hatchery cohort followed by a major reduction in the sport and troll catch per effort of that cohort suggest that hatchery stocks may already comprise a very large portion of the total Georgia Strait chinook population.

Since sustained high exploitation rates will extinct all but the most productive stocks (hatchery stock), these data should be used to support strict measures to reduce the exploitation rate on wild chinook stocks. Of the present sport regulations, the increased minimum size limit is the only regulation which has significantly reduced chinook catch. However, since some of the hooked and released fish will die and most of the survivors will be removed when they reach legal size, this regulation produces little or no change in the exploitation rate or the fate of wild stocks. Strictly enforced catch ceilings coupled with accurate in-season catch estimates are the best tools for controlling chinook exploitation in Georgia Strait.

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GLOSSARY

Day Type - There are two different day types, weekend days and midweek days.

Fishing Time Block - There are 16 one hour fishing time blocks in each day. These are defined on the interview data from shown in Figure 3.

Interview Work Block - There are four four-hour interview work blocks in each day.

Stint - Represents a combination of a day type, landing site and two con secutive work blocks on a single day.

Proportion of Active Boat Trips - Short form for the proportion of the days total fishing trips that were active in a fishing time block.

Activity Pattern - The pattern that is generated by plotting the proportion of active boat trips for each fishing time block.

Boat Trip - A unit of fishing effort completed when the vessel owner lands and is interviewed.

Fishing Line Trip - A unit of fishing effort represented by the number of fishing lines used during a boat trip.

Fishing Line Hour - A unit of fishing effort completed each hour a line is actively fished.

Angler Trip - A unit of fishing effort completed when each angler lands their catch.

(Example: A boat lands after fishing four hours with three lines and five anglers. The fishing effort expended was: 1 boat trip or 3 fishing line trips or 12 fishing line hours or 5 angler trips).

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